MARINE ENVIRONMENT PROTECTION COMMITTEE
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ANY OTHER BUSINESS

Report on the use of perfluorooctanesulphonic acid (PFOS) and other surfactants in firefighting foam on board ships

Submitted by Norway

SUMMARY

Executive summary:	This document contains the results of a study conducted in order to gain more knowledge on the use of PFOS and other fluorinated surfactants in firefighting foam in the maritime sector
Strategic direction, if applicable:	Other work
Output:	OW 23
Action to be taken:	Paragraph 7
Related document:	MEPC 73/18/3

Introduction

1 Per-and polyfluoroalkyl substances (PFAS) is the collective term for a group of man-made chemicals that consist of fluorinated carbon chains of various lengths and often contain a functional group that can include oxygen, nitrogen, sulphur, hydrogen and/or other atoms. PFAS have been produced by different companies since the late 1940s for a wide variety of industrial and consumer applications, including firefighting foams on board ships and offshore installations.

2 PFAS have received increased attention in recent years as many PFAS bio-accumulate in the environment and exhibit harmful health and environmental effects. PFAS are stable compounds with a unique combination of physiochemical properties, which make them extremely persistent in the environment.

3 PFOS is a sub-group of PFAS and is regulated internationally by the Stockholm Convention on Persistent Organic Pollutants, and all countries which have signed this treaty are thus obliged to limit the production and use of this chemical.

The use of PFOS and other fluorinated surfactants in firefighting foam in the maritime sector

4 In order to gain more knowledge about the use of PFOS and other fluorinated surfactants in firefighting foam in the maritime sector, Norway commissioned a study in order to gather relevant information. The main goal of the study was to evaluate to what extent ships today have firefighting foam on board containing fluorinated surfactants.

5 However, other elements were also considered in the study, such as relevant regulations, experience from replacement of PFAS-containing foams, use of foam for ships in operations, etc.

6 The full report *The use of Perfluorooctane sulphonic acid (PFOS) and other surfactants in fire-fighting foam on board ships* can be found in the annex to this document.

Action requested of the Committee

7 The Committee is invited to note the information contained in this document when considering document MEPC 73/18/3.

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ANNEX

FLUORINATED SURFACTANTS IN THE MARINE INDUSTRY

Use of PFOS and other surfactants in firefighting foams onboard vessels

The Norwegian Maritime Authority

Report No.: 2017-1129
Document No.: 115PE4L7-2
Date: 2017-12-19

Project name:	Fluorinated surfactants in the marine industry	DNV GL AS Maritime
Report title:	Use of PFOS and other surfactants in firefighting foams onboard vessels	Environment Advisory P.O. Box 300
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Organisation unit:	Environment Advisory	
Report No.:	2017-1129 , Rev. 0	
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Objective: to evaluate to what extent ships today have firefighting foam onboard containing fluorinated surfactants, in particualar PFOS.

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1 EXECUTIVE SUMMARY

Per- and polyfluoroalkyl substances (PFAS) is the collective term for a group of man-made chemicals that consist of fluorinated carbon-chains of various lengths. PFAS have been produced by different companies since the late 1940s for a wide variety of industrial and consumer applications, including firefighting foams onboard ships and offshore installations. PFAS have received increased attention in recent years as many PFAS bioaccummulate in the environment and exhibit harmful health and environmental effects. Perfluorooctane sulfonic acid (PFOS) and Perfluorooctanoic acid (PFOA) are the most well-known and investigated PFAS. PFOS and PFOA are both very persistent, bioaccumulative and toxic, and have been emitted in high quantities.

PFOS was added to the Stockholm Convention on Persistent Organic Pollutants in 2009 and is applicable to ships flagged by a signatory to the Convention. PFOS is also regulated by the EU ship recycling regulation, but only for vessels with the flag of a Member State. Today there are no references to PFOS in maritime regulations such as SOLAS and MARPOL. Proposals to include PFOA and perfluorohexane sulfonic acid (PFHxS) in the Convention have been submitted and the substances are currently under review.

The goal of this study, commissioned by the Norwegian Maritime Authority (NMA), is to evaluate to what extent ships today have firefighting foam onboard containing fluorinated surfactants. To estimate the number of ships in operation that may have fluorinated surfactants in tanks onboard, DNV GL has done a thorough analysis of the DNV GL fleet and generalized the findings to the world fleet[1]. To identify a set of ships in the DNV GL fleet with fixed foam tanks, SOLAS requirements and knowledge of class notations that imply having installed a fixed firefighting system have been used to extract relevant ships from the DNV GL database. To further assess the DNV GL fleet, the documentation for these ships have been reviewed to confirm whether they have foam tanks onboard, to identify foam supplier/manufacturer, the volume onboard, and search for indications for fluorinated surfactants in the foam.

DNV GL has checked ship specific information for more than 250 vessels, and found information on the supplier, type of foam and the volume onboard for most of these vessels. Based on this, the most relevant suppliers were contacted and asked to provide information on the content of PFOS in firefighting foams. Material data safety sheets dated prior to 2012 were not received, but based on literature review and expert advice from the Norwegian Geotechnical Institute (NGI) it is likely that these suppliers to the DNV GL fleet used PFOS as an ingredient prior to ~2002.

Inventories of number of ships that is likely to have PFOS, PFOA, PFHxS and PFHxA -containing firefighting foam onboard were prepared by generalising the DNV GL results to the world fleet by using the share of DNV GL ships that have fixed firefighting foam tanks to the relevant part (ship types) in the world fleet. To determine whether a firefighting foam contains PFOS or not, a threshold level of 0.001% was used, in line with various national and regional regulations.

Figure 1-1 below shows the numbers of ships that likely have PFOS containing firefighting foam concentrate in fixed tanks onboard, based on the ship delivery year. Almost 7 000 ships are likely to have PFOS in the firefighting foam concentrate onboard. Approximately 5 000 ships are likely to have PFOS or traces of PFOS in their firefighting foam. For ships delivered after 2010, it is assumed that a very small percentage of vessels may have PFOS in firefighting foams from the date of delivery. It is presumed that possible replacement of foam will give an insignificant reduction in number of ships that may have firefighting foams containing PFOS (in concentration below 0.001%), because even though tanks are thoroughly clean, PFOS-concentrations above the threshold level can occur. This is due to

[1] IHS data for world fleet in operation. Note that reefers and many sub types of the Miscellaneous, Passenger and Roro main type are not considered relevant based on the findings in section 4.1. Passenger ships are mainly cruise ships and Roro are mainly vehicle carriers.

PFOS being a very strong surfactant, clinging to the surface of the tank and other infrastructure. It should be emphasized that much less PFOS will be emitted to the environment if a tank originally containing PFOS firefighting foam concentrate is replaced with non-PFOS containing, even though the concentration of PFOS is above the threshold level of 0.001%.

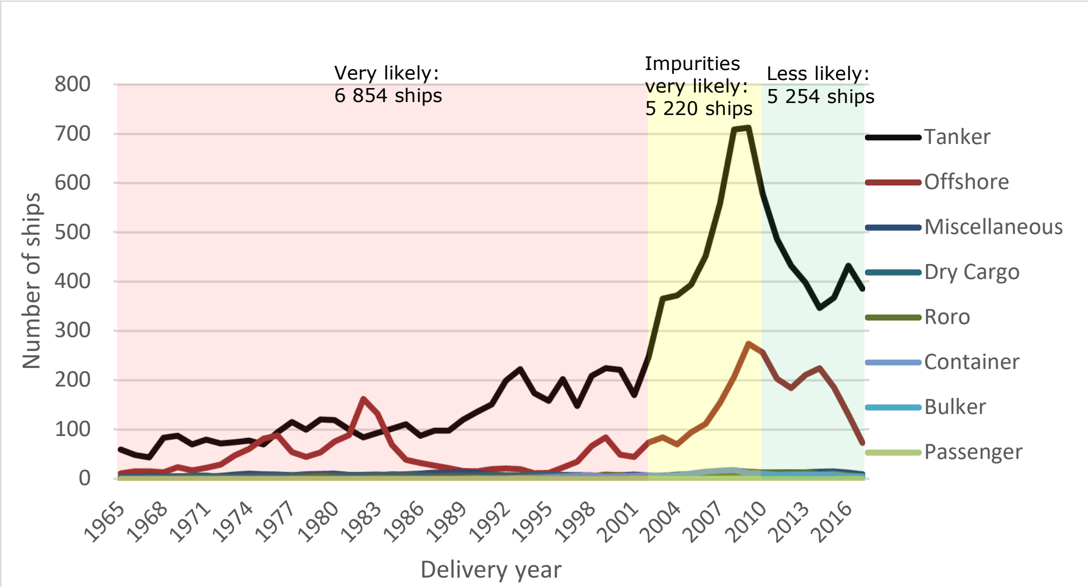


Figure 1-1 Ships and likelihood of foam containing PFOS

For ships built between 2002 and 2010 there is a high probability of PFOA impurities and precursors in firefighting foam in fixed tanks, but also a probability of PFOS. It is difficult to provide an estimate of the proportion of PFOA or PFOS in firefighting foam in this period. Figure 1-2 below shows the number of ships that are likely to have fixed tanks with firefighting foam concentrate onboard containing PFOA impurities and precursors, based on the ship delivery year.

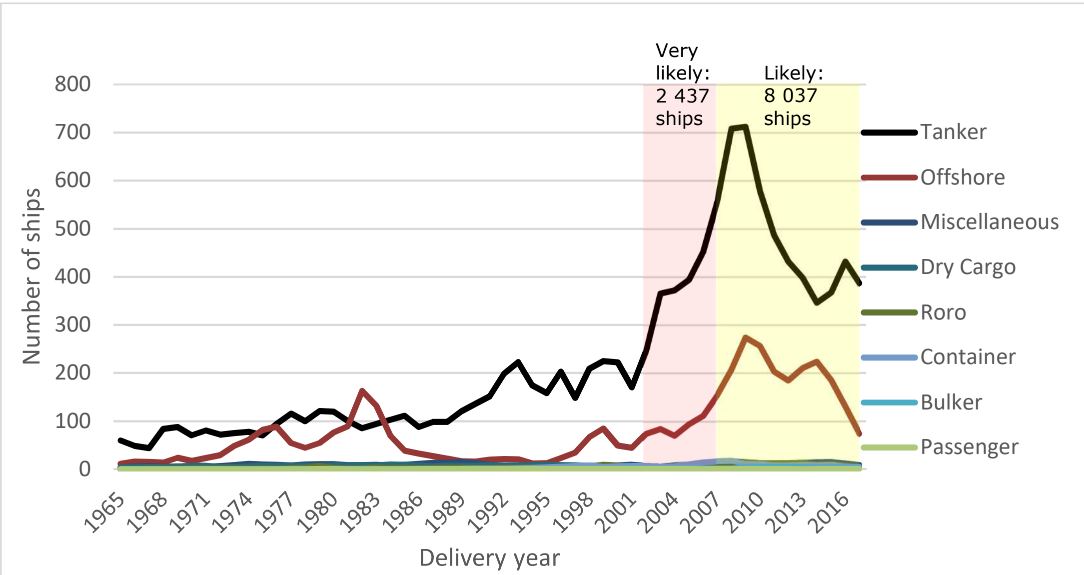


Figure 1-2 Ships and likelihood of foam containing PFOA impurities and precursors

PFHxS and PFHxA are not internationally regulated, and are still used as an ingredient in most firefighting foams. It is assumed that the predominant fluorinated surfactants are PFHxS and PFHxA. Figure 1-3 shows the number of ships that are likely to have fixed tanks with firefighting foam concentrate onboard containing PFHxS and PFHxA, based on the ship delivery year.

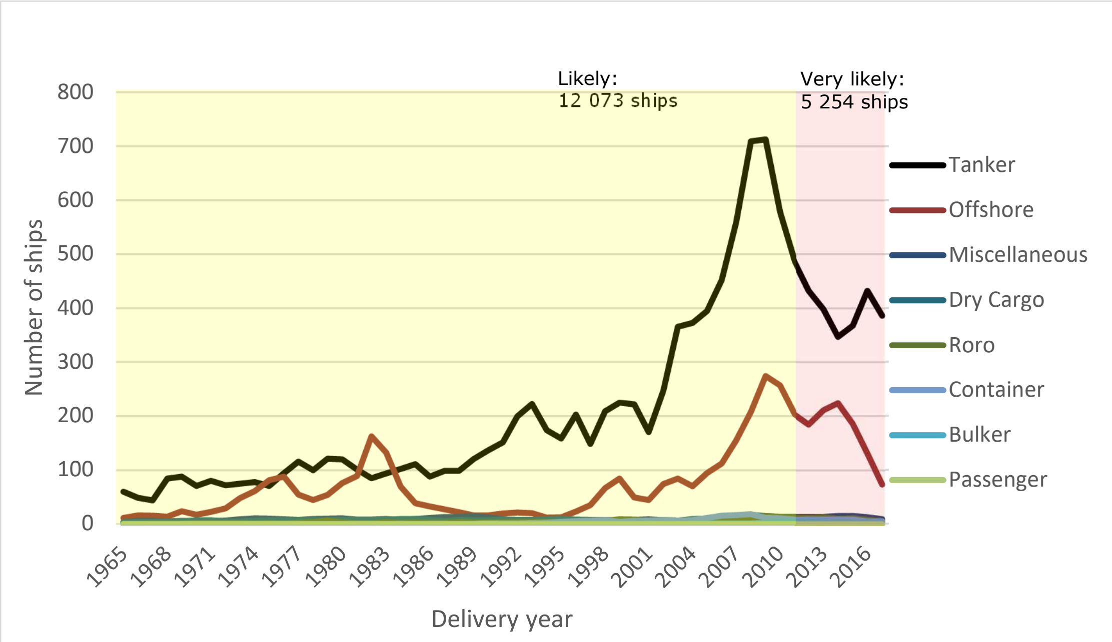


Figure 1-3 Ships and likelihood of foam containing PFHxS and PFHxA

Approximately 17 000 ships have fixed firefighting foam tanks onboard, with volumes in the range from 400 litres to 18 700 litres, containing PFOS, PFOA impurities and precursors, PFHxS or PFHxA or a mixture of these.

Regulators world-wide are now considering restricting more fluorinated organic compounds such as PFHxA, PFBS and PFBA in addition to PFOS, PFOA and PFHxS, and probably more fluorinated organic compounds will be restricted in the future.

References to PFOS and other fluorinated surfactants in maritime legislation such as SOLAS and MARPOL is absent, while PFOS is regulated by the EU ship recycling regulation, for vessels that fly the flag of a Member State. When and if the Hong Kong Convention enters in to force, PFOS may be added to Appendix 1 materials, but it has still not entered into force almost 9 years after adoption. Hence, it might be worthwhile to see if there are ways to implement the Stockholm Convention onboard vessels, both to restrict the use of listed substances, and to ensure safe and environmentally sound downstream waste management.

2 INTRODUCTION

PFAS is the collective term for a group of man-made chemicals that consist of fluorinated carbon-chains of various lengths, and often a functional group that can include oxygen, nitrogen, sulfur hydrogen and/or other atoms. PFAS have been produced by different companies since the late 1940s for a wide variety of industrial and consumer applications, including firefighting foams onboard ships and offshore installations. PFAS have received increased attention in recent years as many PFAS bioaccummulate in the environment and exhibit harmful health and environmental effects. PFAS are stable compounds with a unique combination of physico-chemical properties, which make them extremely persistent in the environment.

PFOS and PFOA are the most well-known and investigated PFAS. PFOA and PFOS are both very persistent, bioaccumulative and toxic, and have been emitted in high quantities. Studies indicate that PFOA and PFOS can cause reproductive and developmental, liver and kidney, and immunological effects in laboratory animals. Both chemicals have caused tumours in animal studies. The most consistent findings from human epidemiology studies are increased cholesterol levels among exposed populations, with more limited findings related to low infant birth weights, effects on the immune system, cancer (for PFOA), and thyroid hormone disruption (for PFOS).

PFOS is strictly regulated in Norway and in the EU, and regulated internationally by the Stockholm Convention on Persistent Organic Pollutants where PFOS is listed in Annex B. It is possible for a signatory to the Convention to apply for certain exemptions. The Convention does not specifically refer to ships or international shipping in the context of such exceptions. The Convention is applicable to ships flagged by a signatory to the Convention. While PFOS has been listed since 2009, PFOA and PFHxS have been proposed for inclusion in the Convention and the substances are currently under review. The Parties to the Stockholm Convention have taken measures to restrict, and in many cases, eliminate the use of PFOS in firefighting foams on-shore. However, there are few indications that Parties have taken measures to restrict the use of PFOS onboard vessels. In addition, there are no references to PFOS in maritime regulations such as SOLAS and MARPOL (NMA pre-study).

There is little available knowledge on the subject. One study on behalf of the Norwegian Pollution Control Authority (SFT) from 2005 found that only one ship had PFOS containing firefighting foam. However, the study included a survey where only 13 tank ships and 3 ferries responded. Another study, conducted by DNV GL on behalf of EMSA in 2017 suggests that PFOS is still found onboard vessels. Fluorinated surfactants have not only been used in aqueous film-forming foams (AFFF), but also in film-forming fluor-protein foams (FFFP), alcohol-resistant aqueous film-forming foams (AR-AFFF) and in alcohol-resistant film-forming flour-protein foams (AR-FFFP). These types of foams have been used and may still be in use onboard commercial vessels.

The aim of this study, commissioned by the Norwegian Maritime Authority, is to establish an overview of:

- the use of PFOS and other fluorinated surfactants in firefighting foams used onboard ships and mobile offshore units
- the type of foam that is delivered to new buildings
- how foams are used under drills and testing of equipment
- when and how foam is replaced
- waste management of discarded foam

We have reviewed existing literature, collected information from internal databases, interviewed suppliers of firefighting foams to the maritime industry, and conducted an informal dialogue with crew onboard mobile offshore units and ships. We have also received expert advice from NGI (the Norwegian Geotechnical Institute). Based on this, the report presents an overview of the number of ships that are likely to have PFOS-containing firefighting foam onboard.

This report gives a short introduction to the methodology in Section 3, while Section 4.1- 4.9 presents the background information for the inventory in Section 5. Practices and issues related to the replacement of foam is presented in Section 6, while Section 7 provides an overview of relevant regulations.

3 METHODOLOGY

The goal of this study is to evaluate to what extent ships have firefighting foam containing fluorinated surfactants onboard today.

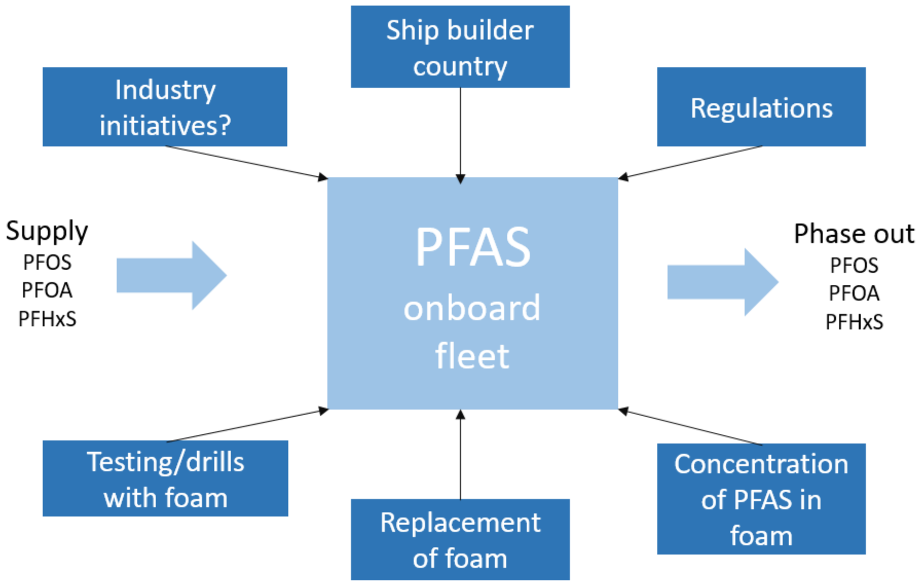


Figure 3-1. Identified factors for occurrence of fluorinated surfactants onboard vessels

Figure 3-1 presents identified factors for occurrence of fluorinated surfactants onboard vessels. Fluorinated surfactants have been used in a range of firefighting foams since the 1960s, but the presence onboard vessels today is not well known.

The project has investigated if there are requirements for fixed firefighting systems for specific vessel types, or for specific class notations, specified in SOLAS, which may indicate the presence of firefighting foam and subsequently the presence of fluorinated surfactants. We have reviewed national, regional and international regulations for the use of firefighting foam containing fluorinated surfactants, as well possible industry initiatives to reduce or phase out the use of fluorinated surfactants.

Ships may have firefighting foam containing fluorinated surfactants from date of delivery, and dependent on shelf-life and drills, may still have it onboard. Frequent fire drills where firefighting foam is used implies that the rate of replacement of firefighting foam increases, and that firefighting foams containing fluorinated surfactants may be phased out faster than if fire drills are performed without using firefighting foam. Based on this, the project has established an overview over required testing in accordance with SOLAS requirements supplemented with possible additional firefighting foam manufactures requirements.

For some hazardous substances, various countries and regions have different threshold values to determine whether a hazardous material is present. For example, some countries determine a product free of a hazardous substance if the level is below 1%, while in other countries the threshold level for the same substance can be much lower to determine it as free of that hazardous substance. Hence, the existence of any threshold levels had to be determined.

The above factors have been established based on extensive literature review, interviews with manufacturers and suppliers, DNV GL databases, experiences reported from personnel working onboard vessels and rigs, and expert advice on biodegradation of fluorinated surfactants.

The project has investigated the use of firefighting foam containing fluorinated surfactants onboard DNV GL classed vessels and prepared an inventory model. Using a bottom-up approach, the findings have been generalized to the world fleet. The description of how data has been collected and put together is described in section 5.

4 FLUORINATED SURFACTANTS INVENTORY: MODEL INPUT

This section presents the background information for the fluorinated surfactants inventory model presented in section 5.

4.1 Requirements for firefighting foam onboard vessels

Firefighting systems onboard vessels can be of various types, including fixed gas systems, fixed water-fire extinguishing systems, or foam fire extinguisher systems. Fluorinated surfactants can be found in foam systems, mainly in aqueous film-forming foam (AFFF).

Foam concentrates used for fixed deck foam fire-extinguishing systems are required for:

- Tankers by SOLAS regulations II-2/10.8 and Chapter 14 of the International Code for Fire Safety Systems (FSS Code), and
- Chemical tankers as specified by SOLAS regulation II-2/1.6.2.1.2 and the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code)

Fixed foam fire-extinguishing systems are also required in machinery spaces according to Chapter 6 of the FSS Code and for portable foam applicators according to chapter 4 of the FSS Code. Based on this and some other typical applications, it is likely that fixed firefighting foam installations are found onboard:

- Tanker for oil
- Tanker for chemicals
- Vessels with helideck
- Low Flashpoint Liquid fuelled vessels
- Vessels with firefighting foam in machinery spaces

Portable foam fire extinguishers can be found in various locations throughout the vessel, generally ranging from 9-50 litres. In the portable fire extinguisher, the foam concentrate is mixed with water, typically 3% foam concentrate and 97% water.

Based on the requirements above, DNV GL extracted relevant vessels in class from its databases. 2735 vessels were extracted. The record of approved cargo ship safety equipment and its annexes were investigated for more than 250 vessels. Due to time and resource limitations, only electronic documents were examined, however, in the case of missing records the correspondence documentation was also examined. In most cases, it was possible to establish supplier, type of foam and number of litres of foam. Documentation showing that foam has been replaced has only been found for one out of 250 vessels.

4.2 Fluorinated surfactants in firefighting foams

Fluorinated surfactants have been used in a range of firefighting foams. The EMSA IHM guidance (2016) indicates, and this is also suggested in interviews with manufacturers and suppliers, that the fluorinated surfactants PFOS may have been used in:

- AFFF (Aqueous film-forming foams): used for aviation, marine and shallow spill fires developed in the 1960s.
- FFFP (Film-forming Fluor-protein foams): used for aviation and shallow spill fires.
- AR-AFFF (Alcohol-resistant aqueous film-forming foams): multi-purpose foams.
- AR-FFFP (Alcohol-resistant film-forming flour-protein foams): multipurpose foams developed in the 1970s.

Per- and polyfluoroalkyl substances (PFAS, $C_nF_{2n+1}-R$) refer to a family of chemicals that have been produced since the late 1940s. Due to the strong electronegativity and small atomic size of fluorine, the perfluoroalkyl moiety ($C_nF_{2n+1}-$) imparts enhanced properties to molecules (e.g., stronger acidity, higher surface activity at very low concentrations, stability, and/or water- and oil-repellency) compared to their hydrocarbon counterparts. Thus, based on desired functionality and production capability, a large number of PFAS have been developed by different companies over time for a wide variety of industrial and consumer applications (Wang et al, 2017). Figure 4-1 gives an overview over PFAS.

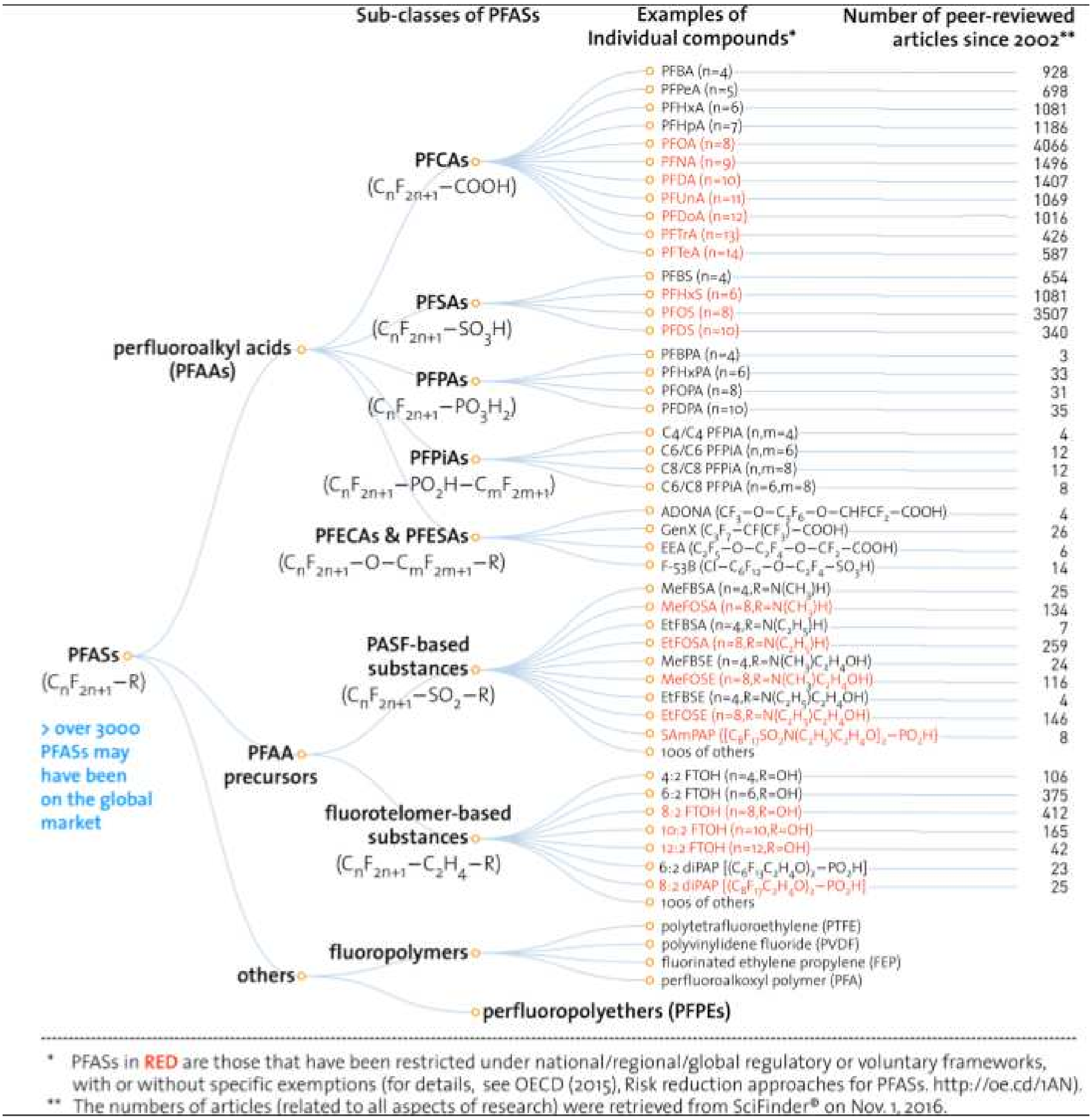


Figure 4-1. "Family tree" of PFAS, including examples of individual PFAS and the number of peer-reviewed articles on them since 2002 (most of the studies focused on long-chain PFCAs, PFSA and their major precursors), from Wang et al. (2017).

AFFF (Aqueous Film Forming Foam) was available for commercial use from the 1960s onward, from different producers. The mixture is complex and in most cases proprietary, but generally it contains a solvent, fluorocarbon surfactants and hydrocarbon-based surfactants (Moody and Field, 2000). The fluorocarbon surfactants used in AFFF are numerous, many of these being novel as the exact composition is not listed in the data sheets of the AFFFs.

PFOS and PFOA are man-made chemicals belonging to the group known as Per- and poly-fluoroalkyl substances (PFAS). PFAS compounds are generally expensive to produce, limiting the application of per- and polyfluorinated compounds to the applications where the compounds' properties are cost-effective. For fuel fires, however, AFFFs containing fluorinated surfactants are some of the quickest acting and best, and are thus chosen despite their relative expense. Further, a relatively low concentration of the compounds is needed to extinguish fire, and a combination of fluorinated and hydrocarbon surfactants gives a preferable mixture for optimal fire extinguishing (Moody and Field, 2000).

The investigation of the records of approved cargo ship safety equipment in the DNV GL database confirmed that the vessels had foam that contained fluorinated surfactants, where information of the type of foam was provided in the record.

4.2.1 PFOS

PFOS was widely used in aqueous firefighting foams (AFFF) due to its film-forming properties. In the mixture, the fluorocarbon surfactant is the most important chemical contributing to the fire extinguishing property (Moody and Field, 2000). The purpose of the surfactant is to reduce the surface tension in the air-foam interface, enabling the foam to make a film atop the burning fuel, suffocating the fire from oxygen and preventing re-ignition (Baduel, et.al, 2015). The film is of a low density and can float on top of most hydrocarbons. Fluorinated surfactants, and in particular PFOS, are some of the best performing surfactants in general, which makes them very effective AFFFs. Also, fluorourfactants, due to their structure, are stable in the high temperatures present in a fire.

PFOS and other PFAS are, as earlier mentioned, present in AFFFs due to their properties in the mixture. PFAS are necessary in the mixture for the foams to pass the requirements issued by some local regulations. For instance, the US Department of Defence, requires that foams used to extinguish gasoline and heptane fires can do so in less than 30 seconds to pass the United States military specification (milspec). US airports are further required by the Federal Aviation Administration to carry AFFF that meets the milspec. The requirements are also met by airports in other nations than the US. Firefighting tests, using both AFFF (containing short chain PFAS) and fluorine-free foam (not AFFF) show that AFFF are more efficient on all fires, except for fires in diesel (FFFC, 2017). Despite of this, many countries have started using fluorine free firefighting foams to reduce the emission of PFAS to the environment, see section 6.1. The time used to extinguish a fire with fluorine free foam may be a bit longer than with AFFF, but to compensate for this at places like airports, reducing the mobilization time to bring the fire extinguishing equipment to the fire is an option.

There are many types of firefighting foams in addition to AFFFs that were available prior to 2002. However, it was early recognized that AFFFs were the most effective for hydrocarbon fires, at least at the time, and therefore AFFFs were the most commonly used for this purpose by the military, airports, harbours etc.

3M was the main producer of AFFF from the 60s until they phased out their production of AFFF in 2001. 3Ms AFFF contained fluorosurfactants produced by the electrochemical fluorination (ECF)-method, consequently containing PFOS. As reported by Darwin (2004), the AFFFs produced by 3M amounted for approximately 75 % of the AFFF stockpiled on Military bases in the US. It should be noted that the ECF method produces many PFAS impurities, in addition to PFOS. Therefore, PFOS-based AFFFs would contain traces of other PFAS. Other producers of AFFF in Europe and the US primarily use the telomerisation method, to make fluorotelomer-AFFFs. The telomerisation method produces fluorotelomers, and cannot be used to produce PFOS. Therefore, some users may have chosen fluorotelomer based AFFF rather than PFOS. Telomers with 8 carbons, like 8:2 FTS, in flourotelomer-AFFF can however oxidize when exposed to fires or the environment to form PFOA.

Some polyfluorinated compounds have been shown to have the potential to degrade to PFOS (Martin et al., 2010). The shift towards fluorosurfactants with a six-carbon chain length in more recent AFFF formulations does exclude the breakdown to PFOS or PFOA; however, there can still be impurities present, of especially PFOA or PFOA precursors, that can give detection of these compounds in environmental samples.

Place and Field (2012) have done a survey, testing AFFFs from different producers, trying to determine the chemical composition, specifically for its composition of fluorosurfactants. As for the suppliers contacted in connection with this report, the accurate composition is not given in the producers MSDS, and the exact composition is proprietary.

Analysis of 19 3M AFFF produced between 1988 and 2001, showed that all foams contained C6-C8 sulphonates (PFOS, PFHxS), but no perfluoro carboxylates (for instance PFOA) were found (Place and Field, 2012). The samples in the study were received from US Air Force and Navy bases within the US, but there is no reason to believe that the same 3M AFFFs were also used elsewhere.

Fire-fighting foam concentrate historically had a PFOS content of 0,5 - 6 % (Unido, 2017). This concentrate is mixed with typically 94% or 97% water to produce the foam.

4.2.2 PFOA

PFOA has a chain length of eight carbons, and an acid group (-COOH) as a functional group. Like PFOS, PFOA can spread rapidly in the environment. PFOA, like PFOS, is found to be very persistent in the environment, likely to bioaccumulate in food chains, and may cause adverse health effects in organisms (Vierke et.al, 2012).

PFOA was an ingredient in early formulations of AFFF, but was not the main fluorosurfactant with these formulations. PFOA is found as an impurity in many AFFFs, and also in currently made telomere based AFFFs (Seow, 2013).

Polyfluorinated compounds with eight carbon chain length, like 8:2 FTS, have a tendency to oxidize to PFOA in the environment (Seow, 2013). So even though PFOA is not detected in many telomere based AFFFs (Place and Field, 2002), it can be detected after the AFFF has been released into the environment, or exposed to fire, due to precursors being oxidized to form PFOA.

Through the PFOA-stewardship program, initiated by the US EPA in 2006, there was a phase out of eight carbon telomers in consumer products and in AFFF. The goals for the program were to have a 95 % reduction of emissions of PFOA, precursors to PFOA and also of all homologues with longer chain length, by 2006. By 2015, all emissions of these compounds should have ceased. Among the companies signing to the Stewardship Program were producers of AFFF such as 3M and DuPont2 (now Chemours). All participating companies stated that they met these goals, mostly by stopping the production of long-chain PFAS, transitioning their production to shorter chain homologues (US EPA Fact Sheet: 2010/2015 PFOA Stewardship Program).

Therefore, AFFFs produced prior to 2006, may contain C8 telomers that will be a source to PFOA in the environment. After 2006, there is a lesser chance of finding C8 and longer chained PFAS in the AFFF commercially available products. In dialogue with Tyco, a dominant supplier of firefighting foam to the maritime industry, it was clear that they just recently started with switching over from C8 to a C6 carbon chain, hence PFOA may be present.

4.2.3 PFHxS, PFHxA and other short chain PFAS

According to a study performed by the Danish Environmental Protection Agency (2015) manufacturers of AFFFs have, over the last several years, been replacing long-chain fluorosurfactants based on PFOS derivatives/precursors or precursor of PFOA with shorter-chain fluorosurfactants such as, but not limited to, PFHxS and perfluorohexanoic acid (PFHxA).

PFHxS has a chain length of six carbon atoms, where the first five are perfluorinated and the last carbon atom contains two fluorines and sulphonic functional group. It is therefore similar to PFOS, only with a shorter chain length. PFHxA is similar to PFOA but with a chain length of six carbon atoms (Danish Environmental Protection Agency, 2015).

PFHxS has been used in coating of various consumer products (carpets, paper and textiles), but have also been used as a surfactant in AFFF (Hertzke, et.al 2012). In the study by Hertzke et al (2012), PFHxS was found in one out of five AFFFs. Due to its use in AFFF, it is quite possibly found on the vessels that are investigated in relation to this report. The compound has further been used as raw-material in production of other PFAS, and can also be found as impurities in manufacturing processes (UNEP, 2017).

At the request of the Swedish Chemicals Agency and the Swedish Civil Contingencies Agency (MSB), Örebro University performed chemical analysis of selected fire-fighting foams on the Swedish market in the autumn of 2014. The aim was to identify the presence of per- and polyfluorinated alkyl substances (PFAS) including precursor compounds. Known PFAS were found in all products analysed, most commonly detected were short chain perfluorinated carboxylates, from low ppb levels up to ppm levels. PFHxA was found in highest concentrations, up to 14 000 µg/kg. Fluorotelomer sulfonic acid with six fluorinated carbons (6:2 FTS) was quantified in all studied products up to 10 000 µg/kg. Bioaccumulating perfluorinated acids ($C \geq 7$) and perfluorinated sulfonic acids were detected less frequent and in lower concentrations.

Filipovic et al. (2015) conducted a study on the distribution of perfluoroalkyl acids (PFAAs) at an abandoned military airfield in Sweden. They found that PFOS and PFOA were ubiquitous in the soil samples. PFOS and PFOA, PFHxA and PFHxS were found in several of the samples of surface water, ground water and tap water. Testing the fluorotelomer based AFFFs used by the US military, Place and Field (2012) found that the main constituents were mainly 6:2 FTS and 8:2 FTS, but also lower concentrations of fluorosurfactants with shorter or longer chain-lengths (Place and Field, 2012) were identified. It is evident that PFHxS and PFHxA have been used in firefighting foams, and can be a final degradation product of other PFAS-precursors in many foams.

It should be noted that PFHxS is one of the shorter chain PFAS introduced in AFFFs, following the phase-out of PFOS and other 8-chain fluorocompounds, like 8:2 FTS. In addition to PFHxS, there is now increasingly found a mixture of diverse short-chain perfluorinated sulphonates and telomers (KEMI, 2015). A concern with modern fluorotelomer-based AFFFs, expressed in the Helsingør Statement, is that shorter chain PFAS are less effective in their use in AFFF, and therefore the amount used in firefighting would be higher, meaning that, in total, the amount of PFAS in the environment will be increased (Scheringer et.al, 2014).

The Madrid Statement documents the scientific consensus regarding the persistence and potential for harm of poly- and perfluoroalkyl substances (PFAS), and lays out a roadmap to gather needed information and prevent further harm. This was published in the May 2015 issue of the journal Environmental Health Perspectives 2017 (http://greensciencepolicy.org/madrid -statement/). The Madrid Statement were signed by more than 230 scientists in over 40 countries.

While the United States Environmental Protection Agency is concerned about long-chained PFAS, including PFHxS, they inform on their internet pages that PFBS and PFHxA are generally less toxic and less bioaccumulative in wildlife and humans than PFCA chemicals with more than eight carbons. However, this opinion may change as more data become available. In the report from the Danish Ministry of Environment (2015), they call for further investigation of the short-chained PFAS such as PFHxA, which is what Germany is currently considering as described in section 4.4.5.

4.2.4 PFAS production methods

There are two principal methods of producing PFAS; electrochemical fluorination (ECF) and fluorotelomerisation. PFOS and related compounds have been produced using ECF (Buck et.al, 2011). 3M was the primary producer until 2002, when the company voluntarily phased out their PFOS-production.

ECF is a method where hydrogen atoms are replaced by fluorine atoms by applying HF to a structure and at the same time introducing an electrical current. The electrical current brakes the C-H bonds, and the H is replaced by a F from the HF-acid (Buck et.al, 2011).

ECF is a relatively crude production method, giving a complex mixture of straight chained and branched molecules, having a range of chain-lengths (Paul et.al, 2009). Generally, though, the result of the ECF method is dependent of the feedstock to the synthesis, feeding a structure of eight carbons into the process gives eight-carbon PFAS as the main product. Still, analysis have shown that the production method has a purity of only 85-87%, the impurities being branched isomers, homologues of other chain lengths, as well as perfluorinated compounds with other functional groups (Buck et.al, 2011).

To synthesize PFOS, first the molecule perfluororoctane sulfonyl fluoride (POSF: $C_8F_{17}SO_2F$) is produced by ECF. POSF was also used directly into products, in addition to PFOS synthesis. As shown in Figure 4-2, Estimated Production volume per year of PFOS (1970-2002), 3M is accountable for most of the world's production of PFOS, until their phase-out in 2002. Other, much smaller producers of PFOS, existed in Europe and Asia (Paul et.al, 2009). PFAS is still produced in Germany, Italy and in fifteen locations in China (Emerging contaminants, 2016).

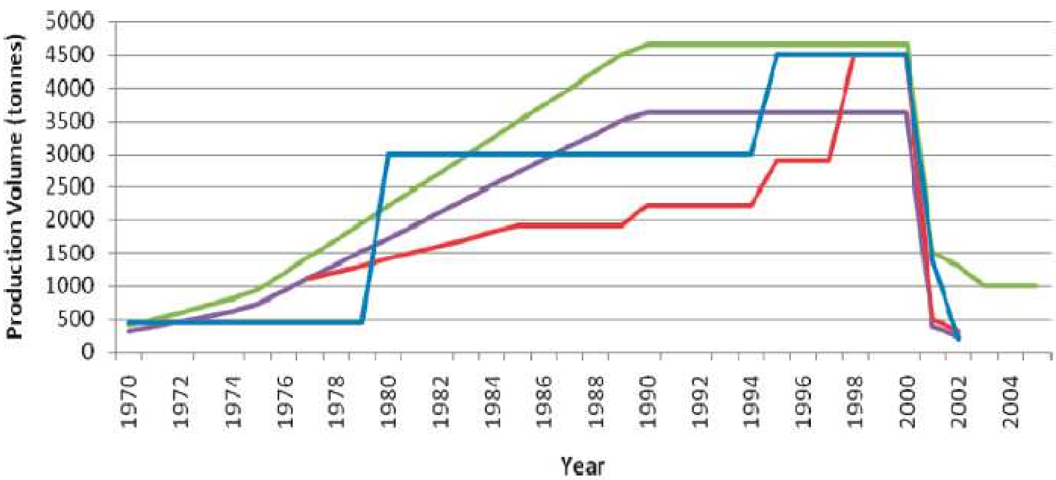


Figure 4-2. Estimated production volume of PFOS (1970-2002), (Paul et.al, 2009). Total amount is shown as the green line, while the estimated volume produced by 3M is shown as the purple line. The blue and the red line is used by Paul et.al (2009) for comparison of the estimated volumes, and are found in other references given in the article.

The fluorotelomerisation method produces even numbered chain length homologous (n, n+2, n+4); odd numbered chain length is not produced. PFOA has been produced mainly using the fluorotelomerisation method (SFT, 2007). Using more recent production methods it is common to insert two methyl groups between the fluorinated tail and the functional group (Seow, 2013). The name of the compound reveals the degree of fluorination to the carbon chain, i.e. 6:2FTS has six fluorinated carbon atoms, and two carbons with hydrogen carbons, before ending in a sulfonate group. Telomer based AFFF cannot degrade into PFOS. As mentioned above, the fluorotelomer based AFFFs do not contain PFOA as a main ingredient, but can still contain trace levels of PFOA, as an unintended by-product (Seow, 2013; Vierke et.al, 2012), as 8:2 FT substances can degrade to PFOA in the environment or when exposed to fire.

4.2.5 Questionnaire to suppliers

Based on the examination of the records of approved cargo ship safety equipment in the DNV GL database, the most frequent suppliers and foam types were established. Five suppliers were contacted by e-mail, and DNV GL had follow up conversation with them on phone and in person. One supplier did not reply to the request. Some of the companies supply the same foam concentrate. One of the suppliers also manufacture foam concentrate, while the others only act as a supplier.

The information provided by the suppliers was forwarded to NGI, whom examined their answers and the material data safety sheets that was provided. DNV GL asked for material data safety sheet prior to 2010, but none were received. The reason is that datasheets were changed in 2012 when MSC.1/Circ.1312 came into force, and the previous versions were apparently not available.

Below follow the anecdotes from the suppliers' emails in *italic*, with NGIs comments given directly underneath.

Kashiwa-Tech:

This supplier provided an MDMS, but no noteworthy anecdotes by emails or other information. NGI added the following comments on the MDMS:

NGI comment: It is likely that all foams from this supplier, except maybe the high expansion foams (Sthamex-SV 2% and Sthamex-SV-HT 2%) to some degree contain fluorosurfactants. This information is gathered from the safety data sheets from the supplier. The AFFF formula contains more flurosurfactants (<10%) than the other given foams (<5% and <1%). There is no information given about the manufacturing process of the surfactants.

Profoam:

Directly from email: "*Our foams do NOT contain neither PFOS nor PFOA, and they are in full conformity with the most strict environmental recommendations. Profoam exists since 2003, so even foams supplied before 2012 do not contain or are far beyond tolerance limits PFOS, nor PFOA*."

NGI comment: Due to the production method, there is a possibility of PFOA-impurity in the foams.

In the datasheets of the AFFF, it is stated that: "*This Formulation contains only telomer-based fluorosurfactants with a short chain (C6 or below) that cannot degrade in the environment into PFOA or other PFCA's. IMPORTANT:C6 telomer-based fluorosurfactants also are not bioaccumulative or toxic to the environment.*"

NGI comment: It is true that C6 fluorosurfactants cannot biodegrade into PFOA (eight carbon chain length), but they can biodegrade into PFCAs with shorter chain lengths (for instance PFHxA). It is however not the case that these compounds cannot bioaccumulate or are not toxic to the environment (e.g. the recent inclusion of PFHxS as an SVHC by ECHA). They are less bioaccumulative and less toxic, and there is also a lot less data available on these compounds, as the focus has been mainly on PFOS and PFOA (Scheringer et.al, 2014). The shorter chain PFAS are as persistent in the environment as their longer chained homologues (Scheringer et.al, 2014).

From email: "*Our foams never contained PFOS. Before 2012 they may have contained very little of PFOA (much smaller than the tolerance limit). See enclosed the European decree on PFOA for reference. The maximum tolerated PFOA in a concentration is 25 ppb (0,025 mg/Lt), and in combination of PFOA-related substances (case of fire-fighting foam) is 1 000 ppb (1 mg/Lt).*"

NGI comment: This comment would be true if they never used formulations from 3M or smaller suppliers that made PFOS-containing fluorosurfactants.

Tyco:

Directly from email: "*We just started with switching over from C8 to a C6 carbon chain*."

NGI comment: If they just started switching, this gives a greater probability of contamination of C8-based foams from the ships that stock foam from this supplier. If the foams are dated after 2002, it is not likely that there is PFOS in the foams, but PFOA is probably present, either as an impurity or degradation product of other ingredients (like 8:2 FTS).

In Bulletin about Towalex foams (General bulletin 15011, dated 2008-10-30): "*All of our foam concentrates are manufactured with telomer based fluorosurfactants and do not contain any added PFOS or PFOA.*"

NGI comment: PFOA can be a by-product/impurity of the telomere method, so even though it is not purposely added to the mixture, it can be present or formulated (as just mentioned).

In Bulletin about Towalex foams (General bulletin 15011, dated 2008-10-30): "*In addition, there has been speculation as to whether or not telomer based surfactants could biodegrade into PFOS or PFOA. Since the majority of our fluorosurfactant use is based on six carbon long chains it is impossible to biodegrade into a longer eight carbon long chain.*"

NGI comment: It is true that C6 fluorosurfactants cannot biodegrade into PFOS or PFOA (eight carbon chain length). There is still the possibility of impurities of longer chain length, of either PFOA itself or precursors to PFOA.

From PFOS letter 1209 V3: "*PFOS is an impurity found in high concentrations in the Electro Chemical Fluorination (ECF) process that produces fluorosurfactant compounds. It is an extremely toxic substance that is bio-accumulative, meaning it has harmful effects to the environment, and is potentially harmful to aquatic, animal and human life. This substance is persistent and research data suggests it is not biodegradable. Note: whilst PFOS is a major issue in firefighting foam production, be assured that all Tyco FS&BP foams are now made with fluorosurfactants obtained by a different process called Telomer, which does not create PFOS*."

NGI comment: PFOS can be an impurity in the synthesis of other PFAS produced by the ECF method, even short chain PFAS; as ECF was the main method of synthesizing PFOS. That they switched to Telomer products implies that their products could contain PFOA as an impurity, PFHexA as an ingredient, or substances that degrade to either of these and shorter fluorotelomer acids.

Survitec Group: Supply the same foam concentrate as Kashiwa-Tech and Tyco.

It is not possible, based on the received information from suppliers to determine when they used PFOS in firefighting foams and when it was phased-out of their products. What is clear is that foams produced today may contain C6 fluorosurfactants that biodegrade into PFCAs with shorter chain lengths (for instance PFHxA). These compounds can also bioaccumulate and be toxic to the environment.

4.2.6 Foam concentrates that historically contained PFOS

Initially DNV GL planned to use the material data safety sheet of the foam in the fixed tanks to determine the presence of PFOS, but as none MDSD were received dated prior to 2012, a different approach was required. After studying various documents from manufacturers and environmental authorities it is evident that PFOS was used in firefighting foam concentrates as follows:

- Solberg from 1990-2001 (http://www.miljodirektoratet.no)
- 3M from the mid ~1965 to 2002 (https://yosemite.epa.gov/opa/admpress.nsf)
- Tyco up to 2000 (Tyco, 2009)
- Dr Sthamer until 2003, after 2003 less than 50mg/kg PFOS is expected (Dr. Sthamer, 2011)

These manufactures represent the majority of the foam manufacturers that delivered foam concentrates to vessels in the DNV GL database, hence it is likely that foams delivered onboard vessels prior to ~2002 can contain PFOS. Replacement of foam and how this impact the presence of PFOS is addressed later in this chapter.

4.3 Industry initiatives

Possible industry initiatives to reduce the use of PFAS in firefighting foams were examined, and a reference was found to 3M and the United States Environmental Protection Agency (EPA). Following negotiations between EPA and 3M, 3M announced in 2000 that it would voluntarily phase out and find substitutes for PFOS used to produce a range of products within 2002. 3M data supplied to EPA indicated that these chemicals are very persistent in the environment, have a strong tendency to accumulate in human and animal tissues and could potentially pose a risk to human health and the environment over the long term (https://yosemite.epa.gov/opa/admpress.nsf). After 2002 there have been various initiatives from manufacturers, national regulations and international regulations to prohibit the manufacturing and use of PFOS.

In addition, the Fluoro Council, the Global Industry Council for Fluoro Technology, represents leading companies that manufacture, formulate or process Fluoro Technology products and promotes the sustainability of those products. FluoroCouncil and its members are working with regulatory authorities and other stakeholders worldwide to innovate and drive increasingly sustainable Fluoro Technology solutions, including the global transition from long-chain PFAS to alternatives such as short-chain fluorochemicals. According to the Fluoro Council short-chain fluorochemicals are alternatives to the long-chain PFAS that provide the same valuable properties, but with improved environmental and human health profiles.

The Fire Fighting Foam Coalition (FFFC) is a non-profit trade association formed in 2001 to focus on issues related to the efficacy and environmental impact of firefighting foams. They argue that all modern AFFF agents contain fluorotelomer-based fluorosurfactants and that fluorotelomer-based AFFF agents are the most effective foams currently available to fight flammable liquid fires. They explain in their fact sheet on AFFF that fluorotelomer-based foams are not made with PFOA or any PFOA-based products, but may contain trace quantities as an unintended by product of the surfactant manufacturing process. Further on it is stated that the short-chain (C6) fluorosurfactants that have been the predominant fluorochemicals used in fluorotelomer-based AFFF for the last 25 years are low in toxicity and not considered to be bio-accumulative based on current regulatory criteria.

The documentation reviewed shows that the major manufactures of firefighting foams no longer produce firefighting foams with PFOS and that they are not made with PFOA or any PFOA-based products, but may contain trace quantities as an unintended by product of the surfactant manufacturing process. Both the Fluoro Council and the FFFC argues that short-chain (C6) fluorosurfactants are low in toxicity and not considered to be bio-accumulative based on current regulatory criteria. The regulatory criteria may however change with further investigations of the properties of short-chained fluorosurfactants, such as PFHxA, which Germany is currently considering, see section 4.4.3.

4.4 Regulations

Prior to requesting DNV GL to perform this study, NMA had researched Norwegian, international and maritime regulations with regards to PFOS, PFOA and other fluorinated surfactants, and found that PFOS is strictly regulated in Norway and EU, and regulated internationally by the Stockholm Convention where PFOS is listed in Annex B. In the sub sections below, descriptions on the current regulatory regime are presented.

4.4.1 Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants (POPs) was adopted on 22 May 2001 and entered force on 17 May 2004. The information in this section is mainly derived from webpages of the Stockholm convention (http://chm.pops.int/). The Stockholm convention is applicable to ships. Specific obligations are associated with the POPS listed in Annexes A, B and C, and some exceptions apply in certain circumstances. PFOS was listed under Annex B at the fourth meeting in May 2009. Parties must take measures to restrict the production and use of the chemicals listed under Annex B considering any applicable acceptable purposes and/or specific exemptions listed in the Annex. Acceptable purposes may be decided by the Conference of the Parties when it adopts a decision amending the Annexes to the Convention to list a new chemical. Firefighting foam is listed as an acceptable purpose for the use and production of PFOS, its salts and PFOSF in part I of Annex B.

In accordance with paragraph 1 of Part III of Annex B to the Convention, if a Party not listed in the Register determines that it requires the use of PFOS, its salts or PFOSF for the acceptable purposes listed in part I of Annex B, it shall notify the Secretariat as soon as possible to have its name added to the Register. Furthermore, in accordance with paragraph 5 of part III of Annex B, the Conference of the Parties evaluates the continued need for these chemicals for the various acceptable purposes and specific exemptions based on available scientific, technical, environmental and economic information. The process for the evaluation was adopted by the Conference of the Parties in decision SC-6/4 and amended by decision SC-7/5.

In accordance with paragraph 6 of part III of Annex B, the first such evaluation took place in 2015 at COP-7. By its decision SC-7/5, the Conference of the Parties concluded that Parties may need to continue to produce and use PFOS, its salts and PFOSF for acceptable purposes as provided in part I of Annex B and consequently need to notify the Secretariat of their intention to produce and/or use those chemicals for those purposes. It is therefore currently possible for a Party to notify the Secretariat of its intention to produce and/or use PFOS, its salts and PFOSF in fire-fighting foam. The next evaluation shall take place at the ninth meeting of the Conference of the Parties in 2019.

The specific exemptions available for other applications of PFOS, its salts and PFOSF, such as photo masks in the semiconductor and liquid crystal display industries are time limited. Pursuant to Article 4 (4) of the Convention, registrations of specific exemptions expire five years after the date of entry into force of the Convention with respect to that chemical unless an earlier date is indicated in the Register by a Party or an extension is granted by the Conference of the Parties pursuant to paragraph 7 of Article 4. Pursuant to decision SC-7/1, no new registrations may be made regarding the specific exemptions for the production and use of PFOS, its salts and PFOSF for carpets, leather and apparel, textiles and upholstery, paper and packaging, coatings and coating additives and rubber and plastics. The other specific exemptions remain available to Parties in relation to the use of PFOS, its salts and PFOSF. Further information on the procedure to register acceptable purposes and specific exemptions is available at http://chm.pops.int/Procedures/Exemptionsandacceptablepurposes/tabid/4646/Default.aspx. Currently there is no agreed time-period for acceptable purposes to be phased out. As indicated above, at its seventh meeting, the Conference of the Parties concluded that Parties may need to continue to produce and use PFOS, its salts and PFOSF for acceptable purposes including fire-fighting foam.

In paragraph 4 of decision SC-7/5, the Conference of the Parties encouraged parties to consider, on the basis of information and the availability of alternatives, withdrawing their names from the register of acceptable purposes for production and use of PFOS, its salts and PFOSF, noting, however, that substitution under "acceptable purposes" with regard to fire-fighting foam may be considered after carrying out techno-economical viability assessment and ensuring functionality in various geo-climatic conditions. In paragraph 9 of the same decision, the Conference of the Parties further reminded parties that paragraph 4 (c) of part III of Annex B to the Convention encourages parties, within their capabilities, to promote research on and the development of safe alternatives to PFOS, its salts and PFOSF, and invited parties to submit information on such research and development in the process of information collection for the evaluation to take place at COP-9. The exchange of information relevant to alternatives to persistent organic pollutants contributes to the reduction or elimination of the production, use or release of such POPs.

The Register of acceptable purposes should reflect all acceptable purposes registered by Parties and is regularly updated by the Secretariat. Per this registry, Cambodia, Canada, China, Switzerland, Vietnam and Zambia have registered for exemption for PFOS in fire-fighting foam (http://chm.pops.int/Implementation/Exemptions/AcceptablePurposes/AcceptablePurposesPFOSandPFOSF/tabid/794/Default.aspx). Canada has registered for exemption, but adopted national PFOS Regulations that prohibit the manufacture, import, sale, offer for sale and use of PFOS or products containing PFOS, unless incidentally present, with certain exemptions. After May 29, 2013, the only remaining exemption is for use of AFFF containing PFOS, if the PFOS concentration is less than or equal to 0.5 ppm. Hence, Canada has restricted the use of PFOS, but the threshold level is slightly higher than in other countries, see section 4.6.

China has registered for exemption and still produce PFOS. This is further described under national regulations and discussed in the ship builder section later in this report.

The Swiss Chemical Risk Reduction Ordinance (ORRChem) entered into force in 2005. This Chemical Risk Reduction Ordinance prohibits or restricts the marketing and use of certain hazardous substances on its own or in preparations and articles. Switzerland operates with equal restrictions as found in EU regulations.

Most flag states have ratified the Stockholm Convention except USA, Malaysia and Italy. Italy is obliged to follow EU legislation as a Member State and USA has regulations that restrict the production and importation of PFOS-based products, including firefighting foams. This is further described in the section on national regulations.

The Convention recognises that there are other chemicals that could pose similar risks to human health and the environment, therefore other chemicals may be added to the annexes in the future. Any Party may submit proposal for listing a new chemical in Annex A, B, or C of the Convention. The Persistent Organic Pollutants Review Committee (POPRC) is a subsidiary body to the Stockholm Convention established for reviewing chemicals proposed for listing in Annex A, Annex B, and/or Annex C. Article 8 of the Stockholm Convention entails the reviewing process of new chemicals and Annex D, Annex E and Annex F specify the information required for the review. The POPRC evaluates the proposals and makes recommendation to the Conference of the Parties on such listing in accordance with Article 8 of the Convention.

PFOA and its salts and related compounds were proposed for listing under the Stockholm Convention in May 2015. The POPRC examined the proposal and concluded that PFOA fulfils the screening criteria to be included in the convention: persistence in the environment, bioaccumulation, potential for long-range transport and adverse environmental effects (UNEP, 2015). Further on, the POPRC invited Parties and observers to submit information specified in Annex E and developed a risk profile. Based on the risk profile, the POPRC decided that PFOA its salts and PFOA-related compounds are likely because of their long-range environmental transport to lead to significant adverse human health and environmental effects such that global action is warranted.

If the POPRC decides that a proposal shall proceed, it invites Parties and observers to submit information related to the socio-economic considerations specified in Annex F and develops a risk management evaluation. Based on the risk profile and risk management evaluation, the POPRC recommended (October 2017) that PFOA, its salts and PFOA-related compounds to be listed in Annex B to the Convention.

It is the Conference of the Parties, taking due account of the recommendations of the POPRC, including any scientific uncertainty, that shall decide, in a precautionary manner, whether to list PFOA its salts and PFOA-related compounds in Annex B to the Convention. Further work is expected on PFOA, its salts and PFOA-related compounds by the POPRC at its next meeting to define the need for possible specific exemptions for certain applications in the view of strengthening its recommendation to the Conference of the Parties.

The Conference of the Parties was established pursuant to Article 19 of the Convention. It is the governing body of the Stockholm Convention and is composed of governments of countries that have accepted, ratified or acceded to it. The implementation of the Convention is advanced through the decisions it takes at its meetings. The next Conference of the Parties will be held in Geneva in April 2019. Chemicals recommended for listing by the POPRC have all been included in Annex A, B or C to the Convention, hence it is highly likely that PFOA, its salts and PFOA-related compounds will be listed in Annex B. If listed, Parties must take measures to restrict the production and use of PFOA, its salts and PFOA-related compounds.

PFHxS and its salts were proposed for listing under the Stockholm convention in June 2017. The POPRC was satisfied that the proposal submitted for listing PFHxS, its salts and PFHxS-related compounds to the annexes of the Convention met the required criteria, moving this group of substances to the next stage of the listing process, which requires the development of a risk profile in October 2017. Based on the risk profile, the POPRC will decide if PFHxS and its salts are likely, because of their long-range environmental transport to lead to significant adverse human health and environmental effects, such that global action is warranted. The next meeting in the POPRC will be held in September 2018.

4.4.2 EU regulation

PFOS is regulated by Commission regulation (EU) No 757/2010 of 24 August 2010 amending Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants as regards Annexes I and III. Since June 27th 2011 foam concentrates containing PFOS shall not be used or stored in the EU (applies if concentrations of PFOS is equal to or above 10 mg/kg (0.001 % by weight) when it occurs in substances or in preparations) and PFOS containing materials is considered hazardous in concentrations above 50 mg/kg. The European Parliament has placed a restriction on marketing and use of PFOS and its salts (included in EU REACH Annex XVII - Restriction List in 2009).

PFOA is a persistent, bioaccumulative, and toxic (PBT-) substance, which may cause severe and irreversible adverse effects on the environment and human health. PFOA has a harmonised classification in Annex VI of European Regulation (EC) No 1272/2008 on classification, labelling and packaging of substances and mixtures (CLP) as Carc. 2, Repr. 1B and STOT RE 1 (liver). Due to its PBT and carcinogenic, mutagenic or toxic to reproduction(CMR) properties, PFOA and its ammonium salt (APFO) have been identified as substances of very high concern (SVHC) under Regulation (EC) No 1907/2006 in the European Union (ECHA, 2013a, 2013b).

In the European Union, a restriction on the manufacturing, use and placing on the market of PFOA and its salts, also including substances that may degrade to PFOA and related substances was proposed by Germany and Norway (ECHA, 2014).

PFHxS is a compound of rising concern, due to its environmental persistence as well as its potential bioaccumulation. As of July 2017, PFHxS is added to ECHAs Candidate list of substances of very high concern, included because of its very persistent, very bioaccumulative attributes.

4.4.3 National initiatives and regulations

AFFF currently manufactured or imported into the United States (US) consist of telomer-based short-chain fluorochemicals (that do not contain or break down to PFOS or PFOA) or alternative chemical substances that do not contain long-chain fluorochemicals. However, the Environmental protection Agency's Significant New Use Regulations (SNUR) do not affect the continued use of existing stocks of the PFOS-based chemicals that had been manufactured or imported into the US before SNURs took effect in 2002. More information about PFOS regulation can be found under the Toxic Substances Control Act (TSCA): https://www.gpo.gov/fdsys/pkg/FR-2002-03-11/html/02-5746.htm.

AFFF discharges are subject to various local and state restrictions because some of the AFFF are formulated with PFOS and PFOA which are of concern to the US EPA since they're persistent, bioaccumulative, and toxic. The US EPA has caused many companies to agree to enter a voluntary stewardship program, which had the goal of reducing environmental releases of PFAS to zero by 2015. https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/20102015-pfoa-stewardship-program-2014-annual-progress.

The Australian state of Queensland now has restrictions on the release of any fluorinated organic product to the environment, including Queensland State waters and is considering the potential release by shipping. A key issue is that all polyfluorinated organic substances, promoted by industry as “safe” are toxic in their own right with toxicities in aquatic environments 10 to 10,000 times that of perfluorinated compounds. Polyfluorinated compounds such as fluorotelomers and fluoropolymers are precursors to perfluorinated carboxylates (PFCAs) including PFOA and readily transform to PFCAs in the environment. Australian Queensland regulators regard the potential release of PFAS by vessels in Australian waters as a significant threat and encourage all vessels in Queensland State waters to have appropriate mitigation measures in place to prevent releases to the environment (Queensland Department of Environment and Heritage Protection, 2016).

The Norwegian Environment Agency has published an amendment to Norway’s consumer products regulation to ban PFOA from consumer products and textiles. This entered into force 1st of June 2014 (Norwegian Environmental Agency, 2014). A transitional period, allowing the import and sale of products manufactured before 1 June, will last until 1 January 2018.

In Canada, the screening assessments of PFOA, and its salts and compounds concluded that these substances are harmful to the environment or its biological diversity as defined under paragraph 64(a) of the Canadian Environmental Protection Act, 1999 (CEPA 1999 or the Act).

In Norway, PFHxS has been placed on the priority list for environmental toxins, and will be phased out within 2020. In Australia, the ban on PFOS also restrict other PFAS with possible adverse effect on the environment. A risk assessment found that PFHxS and/or its precursor probably would have adverse effects. Due to its rising focus, there is a probable phase-out of production and use of the compound in the western world.

As previously mentioned, the Fluoro Council and the FFFC argues that short-chain (C6) fluorosurfactants are low in toxicity and not considered to be bio-accumulative based on current regulatory criteria. The regulatory criteria may however change as Germany is currently conducting a risk management option analysis (RMOA) for PFHxA, its salts and precursors because there are concerns that these substances are persistent, bioaccumulative, toxic and relevant to drinking water (http://www.reach-clp-biozid-helpdesk.de). Norway is conducting a RMOA for PFBS while Sweden is investigating PFBA.

The purpose of RMOA is to help authorities decide whether further regulatory risk management activities are required for a substance and to identify the most appropriate instrument to address a concern. RMOA is a voluntary step, i.e., it is not part of the processes as defined in the legislation. For authorities, documenting the RMOA allows the sharing of information and promoting early discussion, which helps lead to a common understanding on the action pursued. A Member State or ECHA can carry out this case-by-case analysis in order to conclude whether a substance is a 'relevant substance of very high concern (SVHC). An RMOA can conclude that regulatory risk management at EU level is required for a substance (e.g. harmonised classification and labelling, Candidate List inclusion, restriction, other EU legislation) or that no regulatory action is required at EU level. Any subsequent regulatory processes under the REACH Regulation include consultation of interested parties and appropriate decision making involving Member State Competent Authorities and the European Commission as defined in REACH. This Conclusion document provides the outcome of the RMOA carried out by the author authority. In this conclusion document, the authority considers how the available information collected on the substance can be used to conclude whether regulatory risk management activities are required for a substance and which is the most appropriate instrument to address a concern. With this Conclusion document the Commission, the competent authorities of the other Member States and stakeholders are informed of the considerations of the author authority. In case the author authority proposes in this conclusion document further regulatory risk management measures, this shall not be considered initiating those other measures or processes. Since this document only reflects the views of the author authority, it does not preclude Member States or the European Commission from considering or initiating regulatory risk management measures which they deem appropriate (www.echa.europa.eu).

China has registered for exemption, in accordance with the Stockholm Convention, for PFOS in firefighting foams, amongst other applications. There was an increase in PFOS producers from 2002 in China with a peak of 13-15 producers in 2006. Subsequently, production volumes of PFOS increased. In 2002, production volume of PFOS was about 30 tonnes in China, increasing to 246.88 tonnes in 2006. Since then, due to the impact of the international policy to restrict or eliminate PFOS-production, production volume of PFOS has declined to about 100 tonnes/year in 2008 (Zhang et al., 2012).

According to Zhang et al. (2012) PFOS and related substances are no longer used in applications such as textiles, carpets, leathers due to international restrictions. Further on, the use of PFOS is very limited in semi-conductors and aviation. Currently, PFOS and related substances are mainly used in metal plating, aqueous fire-fighting foams (AFFFs) synthesis and sulfluramid formulation. The distribution of use in metal plating, fire-fighting foams and sulfluramid applications in 31 provinces of China is shown in Figure 4-3 below.

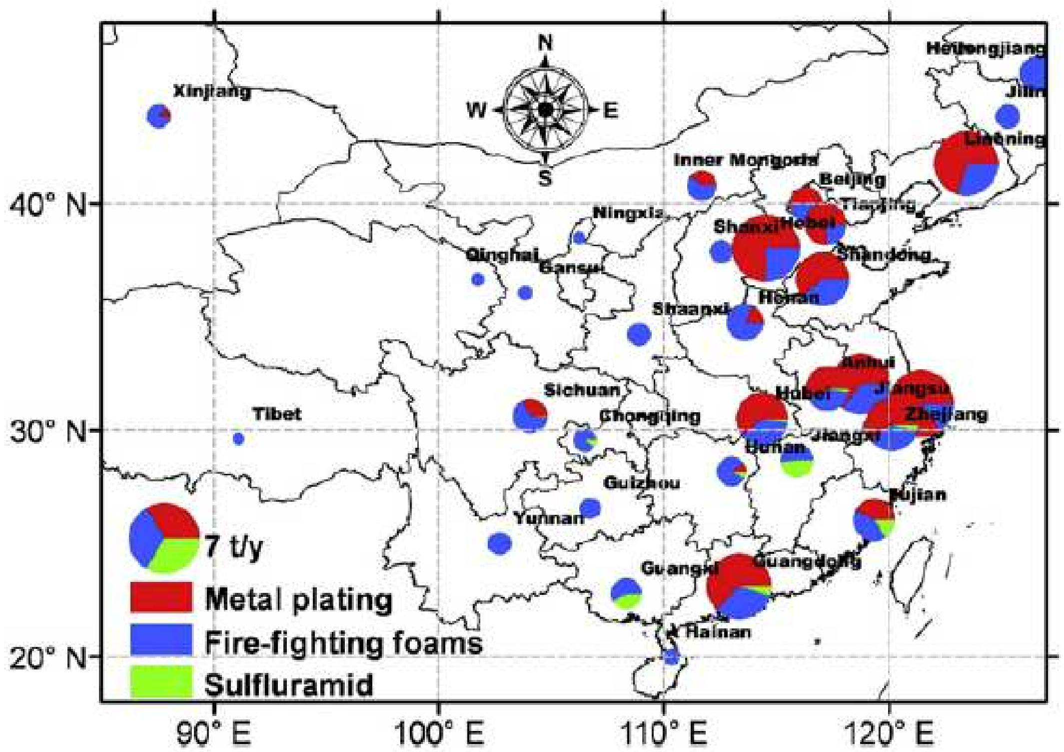


Figure 4-3. The distribution of PFOS amounts used in metal plating, fire-fighting foams and sulfluramid applications in 31 provinces of China (from Zhang et al. 2012).

A survey conducted by the Fire Department of Ministry of Public Security of China indicated that 28% of fire-fighting foams producers were using PFOS as a raw material to synthesize AFFFs. In addition, the percentage of AFFS in the total amount of firefighting foams sold increased from 24.8% to 32.4% (Zang et al.2012). Assuming that the percentage of PFOS among AFFFs product is 0.5%-1.5% (Moody and Field, 2000), the use of PFOS in this application was 25-35 tonnes per year as fluorinated surfactants. AFFFs containing PFOS are especially applied for fire protection in petrochemical, fire brigade and military facilities and similar areas. By contrast, it is a minimal amount used in residential and commercial buildings fire services.

The World Bank's Board of Executive Directors approved in April 2017 a $24.25 million grant from the Global Environment Facility (GEF) to support China's efforts to reduce PFOS in selected sectors and enterprises in a sustainable manner. By converting or closing production lines and facilities and promoting cleaner production, the reduction and phase-out of PFOS in priority sectors such as metal plating, firefighting foam and pest-management techniques and practices for the control of red imported fire ant. Technical assistance will be provided to strengthen the regulatory and policy framework, standards, and capacity building. The project aims to reduce by 44 tonnes the amount of PFOS produced and used yearly, and set up a control and monitoring system for tracking PFOS production and sales. In addition to its global impact, the project is expected to help reduce PFOS exposure for at least 7.2 million people living and working in the PFOS production areas or using PFOS-based pesticides (http://www.worldbank.org/en/news/press-release/2017/04/07/gef-grant-to-assist-china-efforts-to-phase-out-pops).

To summarise the above, PFOS is currently the only PFAS that is internationally regulated by the Stockholm Convention, while PFOA and PFHxS are proposed for inclusion in the Convention. Figure 4-4 shows the timeline for various PFAS legislation.

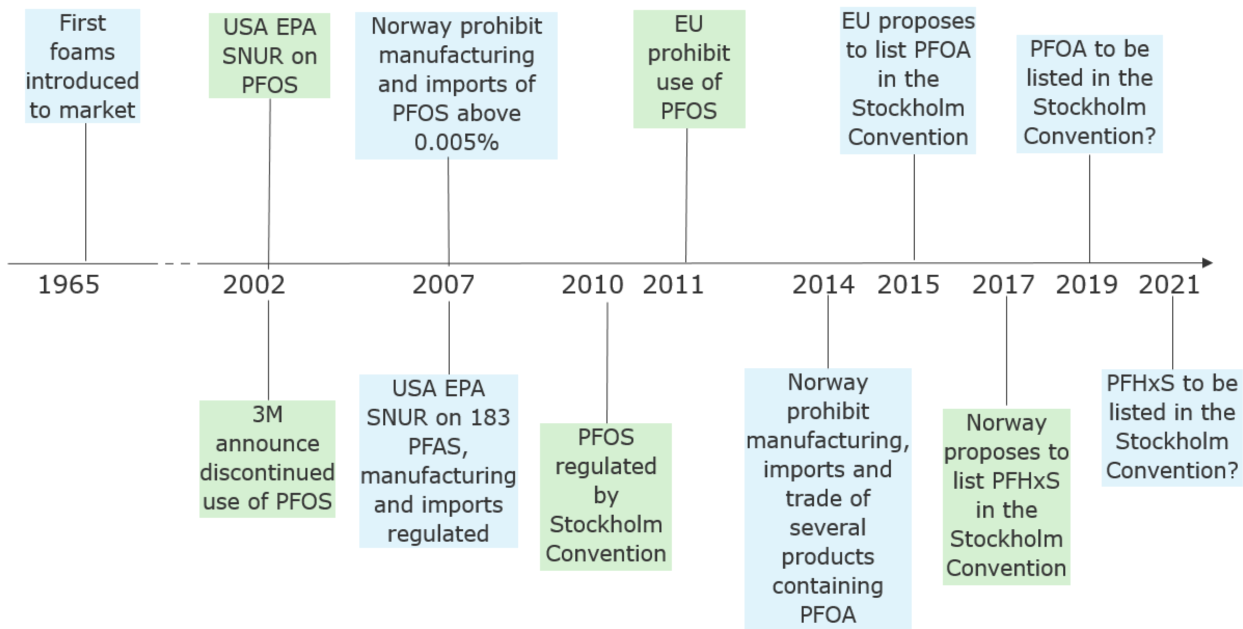


Figure 4-4. Timeline fluorinated surfactants legislation

4.5 Ship builder country

Based on above description of various national regulations and the possibility for countries to register for exemptions with regards to PFOS in firefighting foams, country of build should be considered with regards to the likelihood for PFOS in firefighting foam brought onboard vessels today. It can be expected that there is a higher probability to receive PFOS containing firefighting foam onboard vessel built in a country that have not signed the Stockholm Convention or registered for exemptions in accordance with the Stockholm Convention. Two countries have registered for exemptions for PFOS in firefighting foam in the examined DNV GL database; China and Vietnam. China is a major ship building country, and ~28%

of tankers and offshore vessels in the DNV GL sample were built in China after 2010. Hence, additional checks were required for ships built in in China, while more random spot checks were required for Vietnam as a smaller ship builder nation. The additional checks showed that the major suppliers of firefighting foams were listed as the supplier for ships built in China and Vietnam, except for one entry, where a Chinese supplier was listed. The supplier and the building yard was contacted (in Chinese to ease the correspondence), but a reply was not received from the supplier. The yard replied, and confirmed that this supplier is not among their suppliers, however both the firefighting foam supplier and the yard is listed in the record of approved cargo ship safety equipment. Whether this foam contains PFOS or not is not established, but there is a possibility that firefighting foams supplied by a Chinese manufacturer may contain PFOS today, even though the probability to have foam from a Chines supplier, appears to be low based on the DNV GL sample.

4.6 Threshold levels for detection and reporting

For some hazardous substances, various countries and regions have different threshold values to determine whether a hazardous material is present. As an example, some countries determine a product free of a hazardous substance if the level is below 1%, while in other countries the threshold level for the same substance can be much less to determine it as free of that hazardous substance.

The existence of any threshold levels must be determined, to see if there is a possibility that surfactants may occur as an unintentional trace contaminant, and because of this a threshold level exist for surfactants in firefighting foams. For other substances, this is a challenge as the term 'hazardous free' can be misleading because of different international thresholds that govern and control its precise definition.

The provisions in Article 4(1)(b) of Regulation (EC) No 850/2004 regarding substances occurring as an unintentional trace contaminant has been defined for PFOS to ensure a harmonised enforcement and control of that Regulation, while at the same time guaranteeing conformity with the Convention. By Annex XVII to Regulation (EC) No 1907/2006 PFOS could be used in quantities below certain thresholds. Until further information becomes available, the thresholds in Annex XVII to Regulation (EC) No 1907/2006 for PFOS in articles correspond to a level below which PFOS cannot be meaningfully used while enabling control and enforcement through existing methods. These thresholds should therefore limit the use of PFOS to a level corresponding to unintentional trace contaminants. For PFOS as substances or in preparations, such as in firefighting foams, the threshold level is set to 0.001%. This corresponds to threshold levels in other countries as presented in table 4-1 below.

Table 4-1. Examples on PFOS threshold levels for detection and reporting and hazardous waste

Regulation	PFOS	
	In new products	*Threshold level hazardous waste*
Basel Convention	-	50[1] mg/kg
Australia	0.001%[2]	50[1] mg/kg
EU	0.001%[3]	50[1,3] mg/kg
Norway	0.001%[3]	50[1,3] mg/kg
USA	No concentration provision for products, subject to reporting under the Significant New Use Rule	-
Canada	0.005[4] %	50[1] mg/kg
Switzerland	0.001%[5]	50[1] mg/kg

[1]Technical guidelines for PFOS (Technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF) (adopted by COP.12, May 2015)
[2] https://www.ehp.qld.gov.au/assets/documents/regulation/firefighting-foam-policy.pdf
[3]Commission regulation (EU) No 1342/2014 of 17 December 2014 amending Regulation (EC) No 850/2004 of the European Parliament and of the Council on persistent organic pollutants as regards Annexes IV and V (PFOS)
[4] Perfluorooctane sulfonate, its salts and its precursors (PFOS) and the Prohibition of Certain Toxic Substances Regulations, 2012

[5] Ordinance on the Reduction of Risks relating to the Use of Certain Particularly Dangerous Substances, Preparations and Articles (Chemical Risk Reduction Ordinance, ORRChem)

DNV GL decided to use the most common threshold level of 0.001% to determine whether PFOS is present or not in firefighting foam in the inventory model.

According to the Basel Convention technical guidelines (2015), wastes with a content of PFOS, its salts or PFOSF above 50 mg/kg must be disposed of in such a way that the POP content is destroyed or irreversibly transformed.

Regulation (EC) 850/2004 on persistent organic pollutants (POP Regulation) aims among others at protecting the environment and human health from certain specified substances that are transported across international boundaries far from their sources, persist in the environment, and cause bioaccumulation, by implementing relevant international agreements.

The Regulation's scope is restricted to those substances with POP properties specified in the Annexes of the Regulation. Following Article 7 of the POP Regulation, wastes consisting of POPs, containing or contaminated with them above specific limit values (concentration limit referred to in Article 7(4)(a) – the so called 'low POP-content limit value'), must be disposed of or recovered, without undue delay and in accordance with the provisions laid down in the POP Regulation in such a way as to ensure that the persistent organic pollutant content is destroyed or irreversibly transformed so that the remaining waste and releases do not exhibit the characteristics of persistent organic pollutants.

Disposal or recovery operations that may lead to recovery, recycling, reclamation or re-use of the POPs are prohibited (EC guidance document, 2015). PFOS is amongst the POPs regulated by Regulation (EC) 850/2004.

Further information regarding destruction and irreversible transformation can be found later in this report.

Table 4-2 provides examples on PFOA threshold level where PFOA in articles correspond to a level below which PFOA cannot be meaningfully used. These thresholds should therefore limit the use of PFOA to a level corresponding to unintentional trace contaminants.

Table 4-2. Examples on PFOA threshold levels for detection and reporting

Regulation	**PFOA**	
	In new products	*Threshold level hazardous waste*
Australia	0.005%[1]	
EU	25 ppb/ 1000 ppb in mixtures[2]	3000[3] mg/kg
Norway	0.001%[4]	3000[3] mg/kg
USA	No concentration provision for products, subject to reporting under the Significant New Use Rule	-

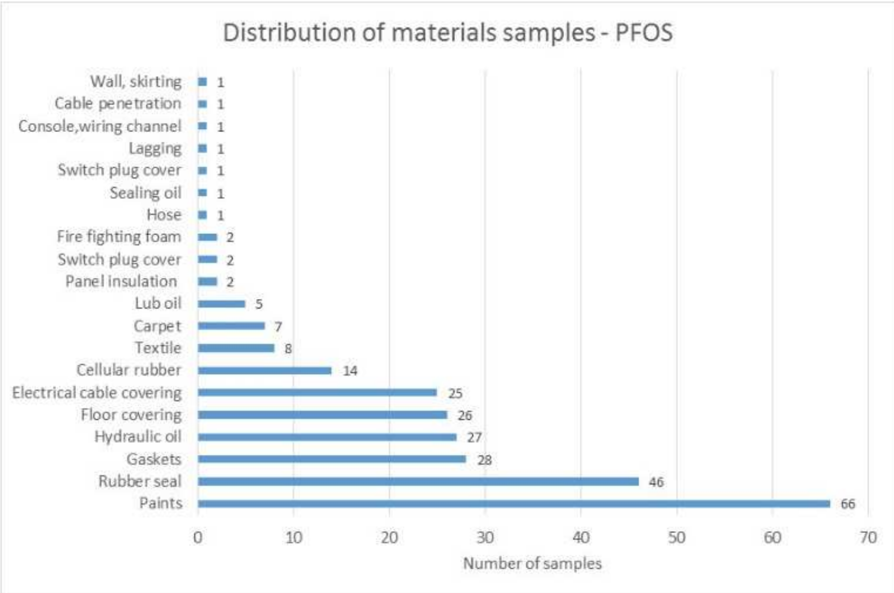
[1] https://www.ehp.qld.gov.au/assets/documents/regulation/firefighting-foam-policy.pdf
[2]Commission Regulation (EU) 2017/1000 of 13 June 2017 amending Annex XVII to Regulation (EC) No 1907/2006 on the registration, evaluation, authorisation and restriction of chemicals (REACH) as regards perfluorooctanole acid (PFOA), its salts and PFOA-related substances. Applies to firefighting foam placed on the marked after 4 July 2020.
[3] Based on H-sentences in the C&L Inventory, European Chemicals Agency and guidance note for classification of hazardous waste from Norsk Forening for Farlig Avfall
[4]Product Regulations, § 2-32 consumer products containing PFOS

As PFOA is currently reviewed for inclusion in the Stockholm Convention, the threshold level for hazardous waste limit may change. Possibly, PFOA will follow the same pattern as other POPs in the Stockholm Convention with a threshold level of 50mg/kg, but that is yet to be determined.

4.7 Current situation of PFOS in IHM's

DNV GL has considered results of material analysis from inventories of hazardous materials for 21 vessels (DNV GL data) where PFOS has been considered. They have mainly been prepared onboard existing ships, but also a few during new building. The ships for which PFOS were sampled, were built between 1977 and 2015.Almost half of these ships were built between 2008 and 2012.

PFOS is not reported, meaning no positive findings, in any out of the 265 samples analysed. An overview of type of materials sampled is presented in Figure 4-5. Paint and rubber seal are the materials most often sampled. Interestingly firefighting foam is only analysed in 2 samples. The reason for the low number of samples from firefighting foam is assumed to be that declarations on PFOS-content is sought for rather than undertaking samples. In most cases the declarations have been for the new foam concentrate onboard vessels, hence not representing the content of the firefighting foam in the fixed tank.



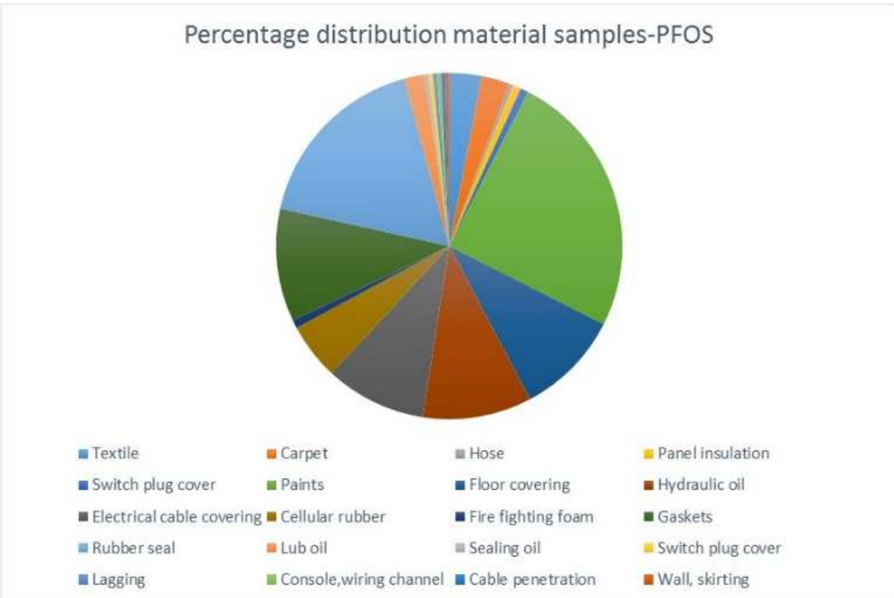


Figure 4-5. Number of different materials analysed for PFOS in IHM assessed by DNV GL

In the analysis Örebro University performed of selected fire-fighting foams on the Swedish market in the autumn of 2014 they found PFOS in two different products from users, but not in the corresponding samples from sealed containers or distributors, indicating probable site contamination from previous fire-fighting products (KEMI, 2015). Hence, it is important to sample foam directly from the tank, and not from a container with new foam concentrate, to get a representative sample.

4.8 Experiences from replacement of foam

There are many examples describing replacement of PFOS-containing firefighting foam with new non-PFOS firefighting foam, where sampling later reveals that PFOS is still present above the threshold level of 0.001%. In addition to the result from KEMI presented above and earlier in this report, there are experiences with replacement of PFOS containing firefighting foams from the operators on the Norwegian Continental shelf which is interesting. Most operators replaced PFOS containing foams in 2006 as it became prohibited to have and use it in concentrations above 0.005% in 2007. In 2013 the permitted threshold level was reduced to 0.001%. Operators were requested by the Norwegian Environment Agency to forward their procedures for replacing the PFOS containing foam, and how they assured that the new firefighting foam contained PFOS below the threshold level of 0.001%. 19 operators forwarded their procedures for replacing PFOS containing foam to other foam types to the Norwegian Environment Agency. Very few operators had included sufficient control measures to assure that the new foam in the tank contained PFOS below the threshold limit. Results from those who analysed samples from the tank, found that the foam could contain less than the threshold level of 0.001% but there were also examples of results above 0.001%. It is assumed that incomplete emptying of tanks and piping, previously holding PFOS containing foam concentrate, may be the reason for detection of PFOS above the threshold level in the new foam concentrates.

Earlier NGI-experience shows that even though tanks are thoroughly clean, PFOS-concentrations above the threshold level can occur. This is due to the PFOS being a very strong surfactant, clinging to the surface of the tank and other infrastructure.

In the inventory model presented later in this report, DNV GL has considered that PFOS in firefighting foam may be present onboard vessels today, for ships built prior to 2002, even though the foam has been replaced. The foam may have been replaced prior to 2002 with PFOS containing foam or with non-PFOS containing foam. But if the foam tank at one point contained firefighting foam with PFOS, it is considered possible to contain PFOS above threshold level today.

Cost of replacing firefighting foam, PFAS-free alternatives and waste management of foam is described later in this report.

4.9 Use of foam for vessels in operation

Foam concentrate may be used (and potentially released to the environment) onboard a ship or unit in operation as part of maintenance, testing and inspections of foam firefighting systems, when training and testing crew/personnel and in emergencies.

4.9.1 Maintenance, testing and inspections

All ships or units are required to have maintenance plans (SOLAS II-2/14 and MODU Code Ch.14) specifying the scope and extent of maintenance, testing and inspections.

The plan is to be based on the guideline from the organization (IMO MSC.1/Circ.1432) and shall ensure that the firefighting systems are available and will work as intended in case of an emergency when the vessel or unit is in operation. The plan shall include relevant requirements from the authorities and should also include recommendations from the system suppliers. The extent of maintenance, testing and inspections depends on type of system, type of foam and the operators onboard.

Requirements from authorities are usually based on the guideline from the organization. The authorities may require additional maintenance, inspection and testing based on national requirements (e.g. CAP 437, ISO 13702). Recommendations from system suppliers are usually based on the guideline from the organization and internationally recognized standards (e.g. NFPA 25).

As a minimum, the scope of maintenance and testing of foam will be limited to annually testing of foam concentrate quality and 5-yearly testing of foam mixing ratios. Most system suppliers also recommend annual function testing of the foam firefighting system. For engine rooms, cargo pump rooms or tank decks, such testing is usually performed without foam. For foam firefighting systems on helicopter decks, most vessels and units aim to satisfy CAP 437. CAP 437 require annual testing of the foam firefighting system which is usually performed with foam.

Informal dialogue with personnel onboard rigs and vessels, indicate that foams are tested more frequently than once a year on helicopter decks. The foam produced is released to sea.

4.9.2 Training and testing of crew/personnel

To ensure proper and efficient use of firefighting equipment and systems, the crew/personnel shall be trained onshore as well as offshore.

Onboard training and fire drills shall be performed per SOLAS II-2/15.2 and MODU Code Ch.14.13.2. Drills are limited and shall incorporate the elements from the onshore training. For mobile offshore units, exercises are performed in addition to drills. Exercises test the emergency response arrangements under as near realistic conditions as possible on the MOU and involves all MOU personnel. Neither drills or exercises require the use of foam unless it is relevant for the drill/exercise.

4.9.3 In emergencies

Foam concentrate is used when systems are released in emergencies. For automatic systems, such release can be due to false alarm.

5 FLUORINATED SURFACTANTS INVENTORY MODEL

Due to missing documentation from suppliers dated before 2012 and time and budgetary constraints, the inventory model represent a best guess estimate based on the current knowledge gathered during this project. We recognise that the inventory model contains uncertainties and that to be certain one would have had to take samples from fixed firefighting foam concentrate tanks onboard all identified vessels.

To estimate the number of ships in operation that may have fluorinated surfactants in tanks onboard, DNV GL has done a thorough analysis of the DNV GL fleet and generalized the findings to the world fleet[2]. To identify a set of ships in the DNV GL fleet with fixed foam tanks we have used SOLAS requirements and knowledge of class notations that imply having installed a fixed firefighting system. To further assess the DNV GL fleet, the documentation for these ships has been reviewed to confirm whether they have foam tanks onboard, to identify foam supplier/manufacturer, the volume onboard, and search for indications for fluorinated surfactants in the foam. The DNV GL fleet study has been generalized to the world fleet by using the share of DNV GL ships that have fixed firefighting foam tanks to the relevant part (ship types) in the world fleet. The generalized results are shown in figures and tables below. Figure 5-1 gives an overview of the approach used to compile an inventory of ships with a fixed firefighting system.

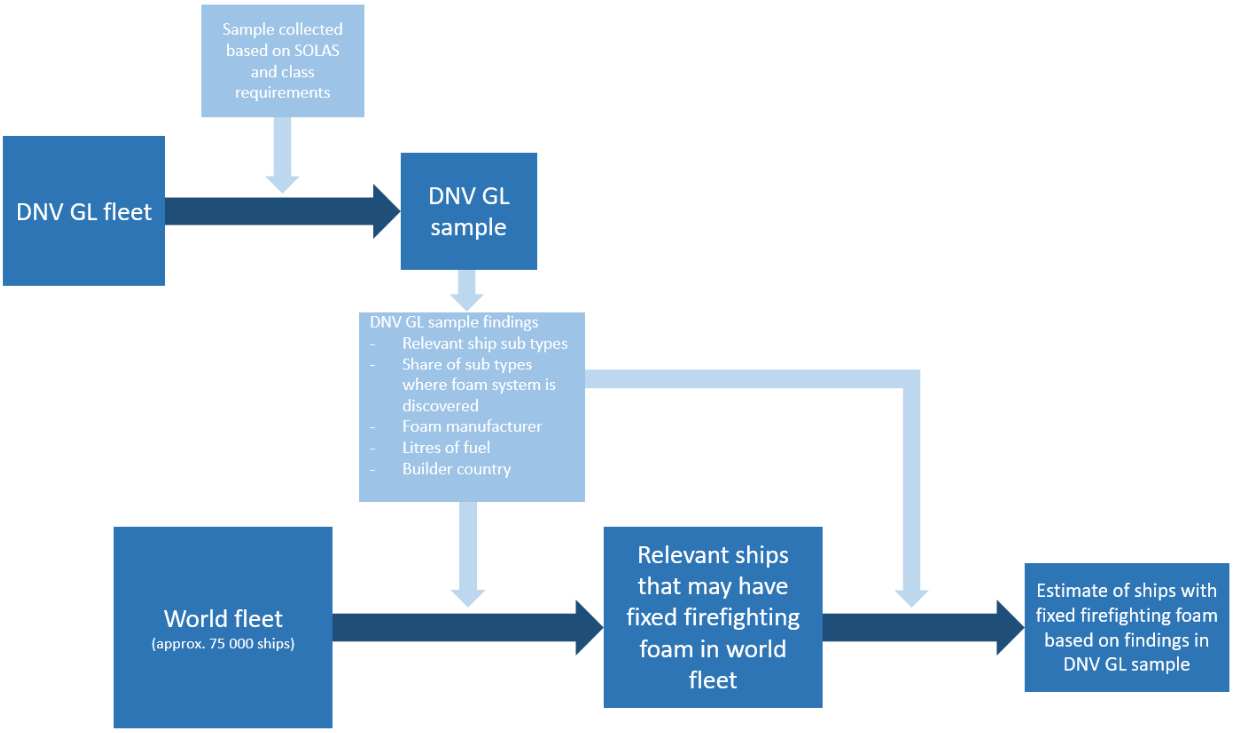


Figure 5-1 Overview of inventory approach

Table 5-1 gives an overview of the number of ships in the world fleet that may have fixed firefighting foam. The share of ships that is likely to have fixed firefighting foam systems onboard is based on the

2 IHS data for world fleet in operation. Note that reefers and many sub types of the Miscellaneous, Passenger and Roro main type are not considered relevant based on the findings in section 4.1. Passenger ships are mainly cruise ships and Roro are mainly vehicle carriers.

findings from the DNV GL fleet study (SOLAS requirements, relevant class notations and review of documentation). Hence, the estimated number of ships with fixed firefighting foam system is given for each ship type.

Table 5-1 Relevant ship types and estimated number of ships with fixed firefighting foam system

Type	Relevant ships that may have fixed firefighting foam in world fleet	Estimate of ships with fixed firefighting foam based on findings in DNV GL sample	Share of relevant ships with fixed firefighting foam from DNV GL sample
Tanker	15 252	11 682	77 %
Offshore	8 299	4 200	51 %
Miscellaneous	8 069	484	6 %
Dry Cargo	13 160	409	3 %
Roro	839	275	33 %
Container	5 134	216	4 %
Bulker	11 041	47	0.4 %
Passenger	452	15	3 %
Total	62 246	17 328	28 %

Figure 5-2 shows number of ships that are likely to have a fixed firefighting foam system onboard by delivery year. The fluctuations show the general development in the fleet. Tankers and offshore ships represent 92 % of ships with fixed firefighting foam systems. For other ship types, only a few ships have fixed firefighting systems and foam tanks, see Figure 5-3 for further detail on number of ships.

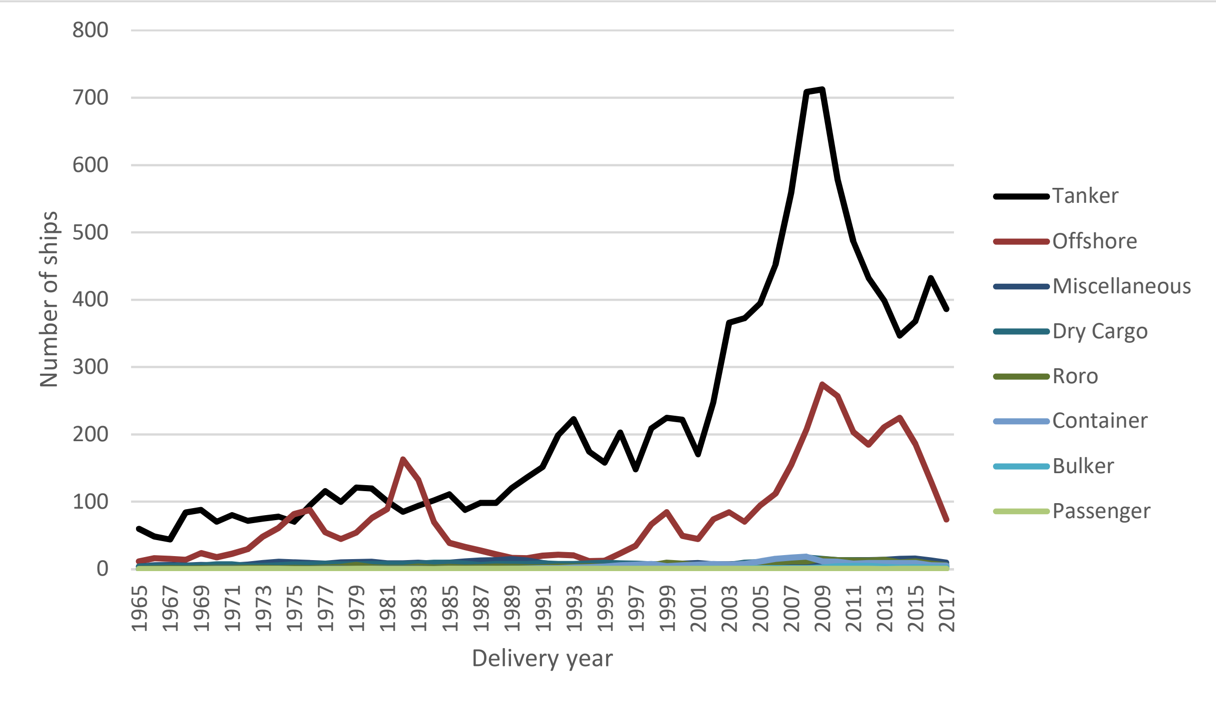


Figure 5-2 Estimated world fleet with fixed firefighting foam tank

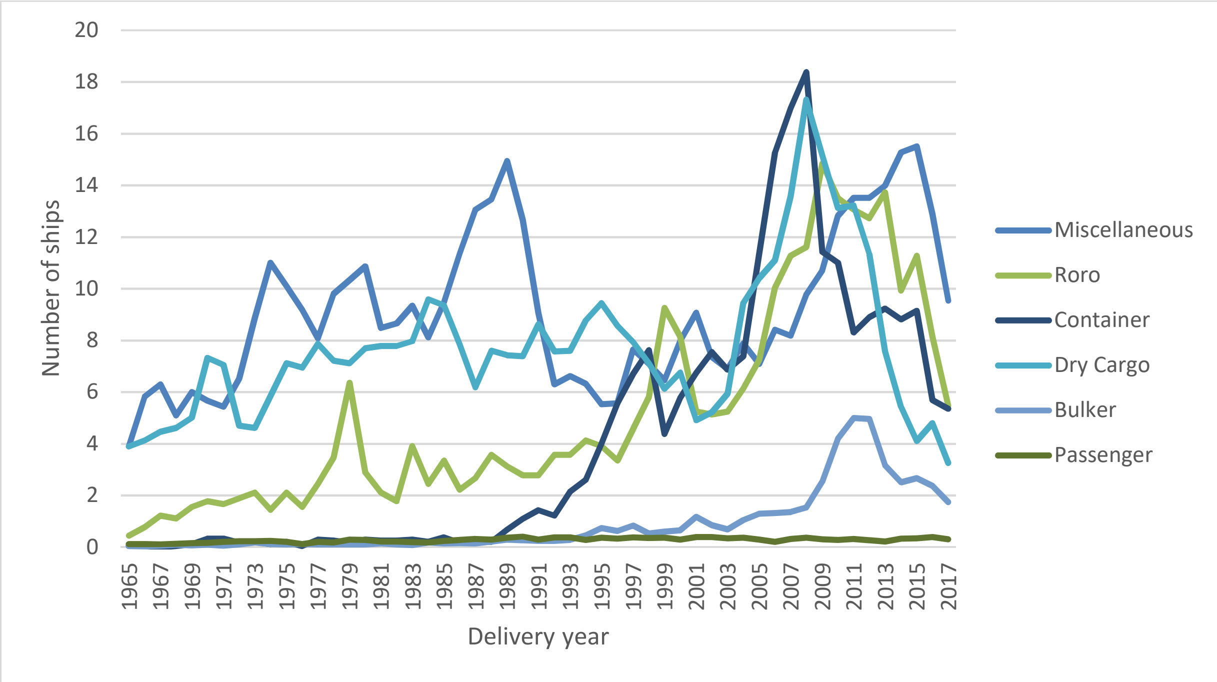


Figure 5-3 Estimated world fleet with fixed firefighting foam tank, other ships than tankers and offshore

5.1.1 Likelihood of PFOS in firefighting foam onboard vessels

To prepare the inventory of PFOS in firefighting foam concentrate, some generalisations were required. Based on results previously presented in this report, only a short summary is presented here:

- Before 2002: The foam is very likely to contain PFOS. Otherwise, it would contain fluorotelomers, which also represent a hazard (e.g. by containing PFOA impurities, and other problematic PFAS, as well as transforming to PFOA in the environment).
- 2002-2010: It is very likely that if the foam is tested, it will show PFOS; there is an increased chance the AFFF contains short chain PFAS (<8 C), e.g. PFHxS. Even though many are no longer using foam containing PFOS, it is very likely that impurities in the tanks will occur since they earlier had AFFF with PFOS. Regarding fluorotelomer surfactants, these will increasingly be replaced with short chain fluorotelomer surfactants.

After 2010: Less likely to contain PFOS and 8C fluorotelomer surfactants. Some impurities may still occur as above. It cannot be excluded that vessels refilling foam might get PFOS onboard, either as an ingredient or as an impurity if they buy supplies in countries where PFOS is still allowed, however the amount is assumed to be small.

Figure 5-4 shows the numbers of ships that likely have fixed tanks with PFOS containing firefighting foam concentrate onboard, based on the ship delivery year. Almost 7000 ships are very likely to have PFOS in the firefighting foam onboard. Approximately 5000 ships are likely to have PFOS or traces of PFOS in their firefighting foam. Approximately 5000 ships delivered after 2010 are less likely to have PFOS or traces of PFOS in their firefighting foam. Approximately one third of tankers and offshore ships built after 2010 were built in China where PFOS in firefighting foams are still allowed, however the DNV GL sample indicates that this is not of a great concern as explained previously. It cannot be excluded that vessels refilling foam might get PFOS onboard, either as an ingredient or as an impurity if they buy supplies in countries where PFOS is still allowed, however the amount is assumed to be small.

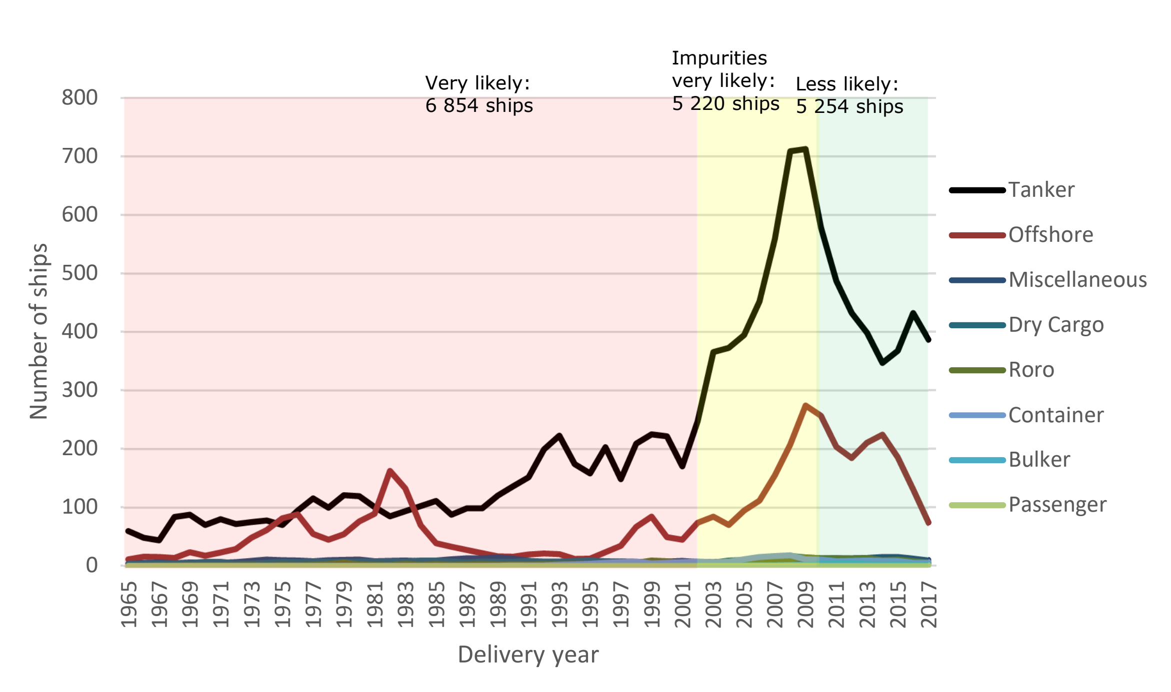


Figure 5-4 Ships and likelihood of foam containing PFOS

Table 5-2 shows number of ships with fixed foam systems by the different time periods.

Table 5-2 Number of ships by time periods

Ship types	Before 2002	Between 2001 and 2010	From 2010
Tanker	4 439	3 813	3 430
Offshore	1 657	1 072	1 471
Miscellaneous	310	66	107
Dry Cargo	258	88	63
Roro	115	72	88
Container	55	95	66
Bulker	10	11	27
Passenger	10	3	2
Sum	**6 854**	**5 220**	**5 254**

5.1.2 Likelihood of PFOA in firefighting foam onboard vessels

To prepare the inventory of PFOA in firefighting foam concentrate, some generalisations were required. Based on results previously presented in this report, only a short summary is presented here:

- Before (and including) 2006: PFOA was an ingredient in early formulations of AFFF, but is not the main fluorosurfactant in the mixture. PFOA is found as an impurity in many AFFFs, also currently made telomere based AFFFs. Fluorotelomer AFFF could produce PFOA as a transformation product in the environment.

- After 2006: There is a lesser chance of finding C8 and longer chained PFAS in the AFFF commercially available. In dialogue with Tyco, a main supplier of firefighting foam to the maritime industry, it was clear that they just started with switching over from C8 to a C6 carbon chain, hence PFOA-precursors and impurities may still be present.

For ships built between 2002 and 2010 there is a high probability of PFOA impurities and precursors in firefighting foam in fixed tanks, but also a probability of PFOS (Dr. Sthamer, 2011). It is difficult to provide an estimate on the proportion of PFOA or PFOS in firefighting foam in this period.

Figure 5-5 shows the number of ships that are likely to have fixed tanks with firefighting foam concentrate onboard containing PFOA impurities and precursors, based on the ship delivery year.

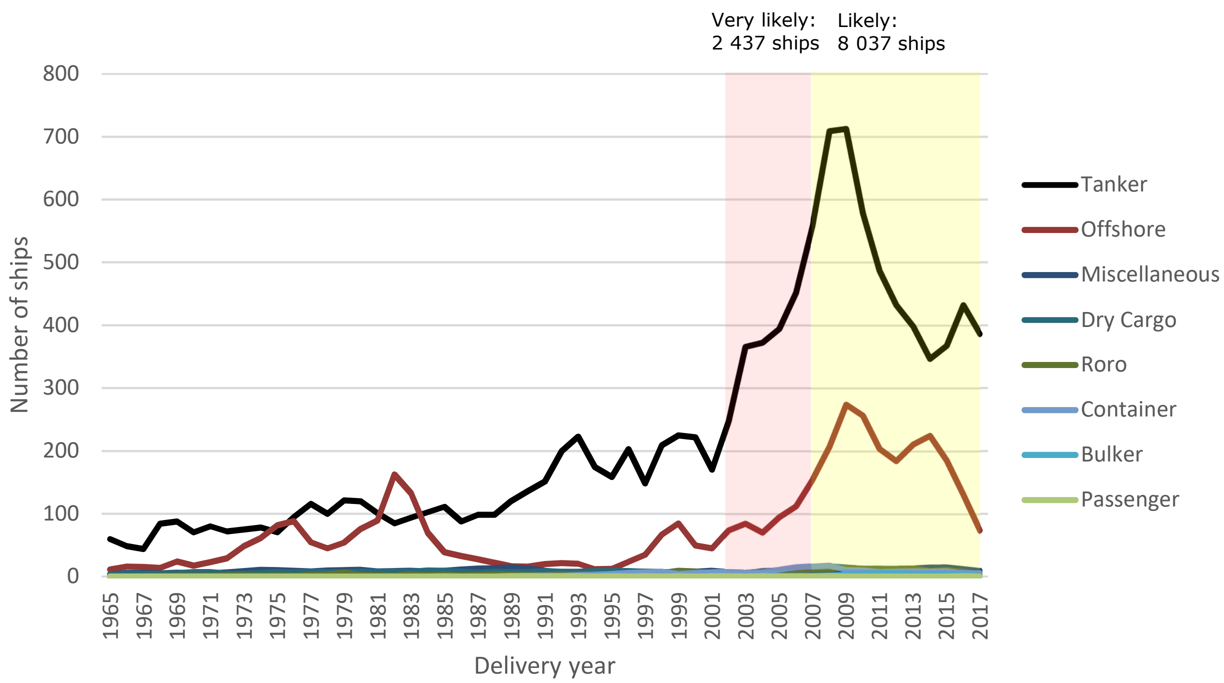


Figure 5-5 Ships and likelihood of foam containing PFOA impurities and precursors

Table 5-3 shows number of ships with fixed foam systems by the different time periods.

Table 5-3 Number of ships by time periods

Ship types	From (and including) 2002 until 2007	From 2007
Tanker	1 833	5 410
Offshore	436	2 108
Miscellaneous	38	136
Dry Cargo	42	109
Roro	34	126
Container	48	113
Bulker	5	32
Passenger	2	3
Sum	**2 437**	**8 037**

5.1.3 Likelihood of PFHxS and PFHxA in firefighting foam onboard vessels

To prepare the inventory of PFHxS and PFHxA in firefighting foam concentrate, some generalisations were required. Based on results previously presented in this report, only a short summary is presented here:

- Before 2010: PFHxS and PFHxA could be present as impurities.
- After 2010: There is an increased chance the AFFF contains short chain PFAS (<8 C), e.g. PFHxS and PFHxA.

PFHxS and PFHxA are not internationally regulated, and are still used as an ingredient of most firefighting foams. For ships delivered after 2010, we could only find one ship in the DNV GL sample suggesting a possible presence of PFOS. It is assumed that this is representative of the world fleet as well, hence it is assumed that a very small percentage of new buildings may have PFOS in firefighting foams after 2010. It is assumed that the predominant fluorinated surfactants are PFHxS and PFHxA. Figure 5-6 shows the number of ships that are likely to have fixed tanks with firefighting foam concentrate onboard containing PFHxS and PFHxA, based on the ship delivery year.

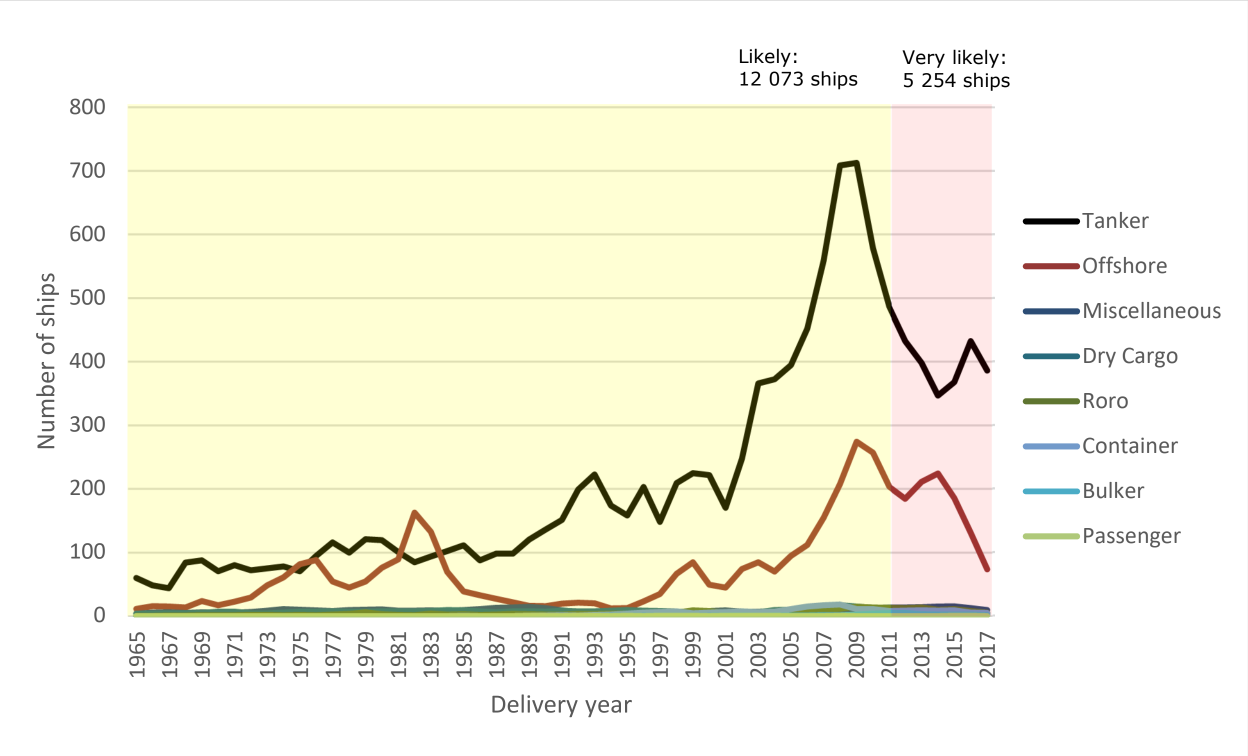


Figure 5-6 Ships and likelihood of foam containing PFHxS and PFHxA

Table 5-4 shows number of ships with fixed foam systems by the different time periods.

Table 5-4 Number of ships by time periods

Ship types	Before (and including) 2010	After 2010
Tanker	8 252	3 430
Offshore	2 729	1 471
Miscellaneous	377	107
Dry Cargo	346	63
Roro	187	88
Container	150	66
Bulker	20	27
Passenger	12	2
Sum	**12 073**	**5 254**

6 REPLACEMENT OF FOAM

6.1 Alternative foam concentrates

Due to raising concern over PFOS and PFOA, these substances have been phased out from most of the new firefighting foams on the market today, but it is still produced for example in China. Some manufacturers and suppliers have developed new firefighting foams that are PFAS-free. There are several examples from various industries where PFAS-foams have been replaced with PFAS-free foams, both onshore and offshore.

The Australian Airservices does not use firefighting foam containing PFAS and stopped using firefighting foam containing PFAS in 2010. The primary function of Airservices aviation rescue firefighting service is to save lives and international firefighting regulations require the use of firefighting foam. From 1988 until the early 2000s, a firefighting foam called 3M Lightwater was used. This product contained PFOS as an active ingredient and other PFAS, such as PFOA. Following increasing concerns about the possible environmental and health impacts of PFOS, in 2003 Airservices changed to another approved firefighting foam called Ansulite that was understood not to contain PFOS or PFOA. It was later found to contain trace amounts of both these chemicals. In 2010, Airservices transitioned to a PFAS-free foam, Solberg RF6, at all airports where they provide ARFF services except for the joint civil-military airports of Darwin and Townsville (www.airservicesaustralia.com, 2017).

Swedavia is a state-owned company that owns, operates and develops Sweden's national basic infrastructure of airports. Swedavia has changed from former PFAS firefighting foam to PFAS-free. Swedavia uses Moussol-FF 3/6 foam, produced by Dr. Shtamer in Germany. The foam has been tested and fulfils the requirements of International Civil Aviation Organization, European Aviation Safety Agency and the International association of fire and rescue service (Swedavia, 2015).

Avinor is responsible for the 45 state-owned airports and air navigation services for civilian and military aviation in Norway. Avinor started to phase out PFOS-containing foams in 2001, and since 2012 PFAS-free foam have been used.

Statoil is an international energy company and the world's largest offshore operator, present in over 30 countries worldwide. Statoil selected Solberg as their partner in the Statoil LOOP Portfolio Program to develop environment-friendly 1% firefighting foam using no fluorinated compounds or other organohalogens, the result being the Rehealing foam 1%. The replacement of foam concentrate is underway and The Kvitebjørn gas and condensate production installation, the platform Njord A and Gudrun are all three equipped with PFAS-free foam according to press release from Solberg (2014). According to Solberg, the Re-healing foam concentrates are intended for use on Class B hydrocarbon and polar solvent fuel fires. Concentrates are available in 3%, 6% and 3x6 ATC formulations. Re-healing foam concentrates can be used to prevent re-ignition of a liquid spill and control hazardous odours, and will improve extinguishment in deep-seated fires.

None of the foams mentioned above have been found in the selection of DNV GL vessels investigated.

Other options may be possible to use onboard vessels, eliminating the use of PFAS-containing foams, such as the compressed air foam systems (CAF-system). This system uses water, foam concentrates and compressed air to generate foam, where Class A foam concentrates can be used. The applicability of CAF systems onboard vessels has not been part of the scope of this project.

6.2 Cost of replacing foam concentrate

Costs associated with replacement of foam is twofold, the disposal of existing foam and the purchase of new foam. For some vessels, it will be required to replace foam based on shelf life, other would be required to change foam as a prerequisite of the Stockholm Convention if the concentration is above 0.001%.

Depending on national regulations, disposal of PFOS containing foam may be as ordinary waste or hazardous waste depending on concentrations. If the concentration of PFOS is above 50 mg/kg (or 3000mg/kg for PFOA), the waste is considered hazardous and specific waste management is required to ensure environmentally sound disposal. This is further described in the next section.

In Norway, there is a very limited number of landfills that will accept PFOS-containing waste and per the Product regulation § 2-9 firefighting foam with a PFOS concentration of 0.001% or above shall be delivered to an approved waste management facility for destruction.

PFOS-containing waste, above the threshold level of 50 mg/kg, shall be declared by EAL-code 160508 in Europe and the cost of disposal is much higher than for ordinary waste. Depending on how the waste is delivered, the price range in Norway is 1000-1500 euros per ton for hazardous waste, while the price for ordinary waste below 50 mg/kg is approximately 200 euros per ton. Incineration of PFAS waste is also a possibility (though pricing for this is unclear).

Depending on type of replacement foam the price range is from 2.2 euros per litre to 16.37 euros per litre for AFFF, alcohol resistant foams are slightly more expensive, while Fluoroprotein foams is like AFFF in the lower price range, but less expensive in the upper price range.

For the vessels investigated in this project, the volumes of foam concentrate are in the range from 400 litres to 18 700 litres, while most vessels have a volume of firefighting foams in the range from 1 000-10 000 litres.

As an example, we consider a tank containing 5000 litres of AFFF. The content of the tank is sampled and analysis confirms that the foam contains PFOS above threshold level of 50 mg/kg. The density of the foam is slightly higher than water, but for this example this is not considered. The cost for waste disposal will, considering the lower and higher price for hazardous waste, be in the range of 5 000-7 500 euros.

Replacing with new AFFF foam will cost in the range of 11 000 euros to 30 000 euros depending on type of AFFF.

In total the replacement may cost 16 000-37 500 euros per average tank. Special deals have not been considered in this example, nor cleaning of tank and piping.

6.3 Destruction and irreversible transformation of PFOS

Basel convention technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with PFOS, its salts and perfluorooctane sulfonyl fluoride (PFOSF) (2015), list two methods for their destruction and irreversible transformation; (a) Cement kiln co-incineration and (b) Hazardous waste incineration for environmentally sound disposal of wastes with a content of PFOS, its salts or PFOSF at or above [50 mg/kg].

Further information regarding the two destruction methods are described in the general technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (Basel Convention, 2015). A short description follows below:

Cement kiln co-incineration

Cement kilns typically consist of a long cylinder of 50–150 metres in length, inclined slightly from the horizontal (3 per cent to 4 per cent gradient), which is rotated at about 1-4 revolutions per minute. Raw materials such as limestone, silica, alumina and iron oxides are fed into the upper or "cold" end of the rotary kiln. The slope and rotation cause the materials to move toward the lower or "hot" end of the kiln. The kiln is fired at the lower end of the kiln, where material temperatures reach 1 400°C–1 500°C. As the materials move through the kiln, they undergo drying and pyroprocessing reactions to form clinker.

Hazardous waste incineration

Process description: Hazardous waste incineration uses controlled flame combustion to treat organic contaminants, mainly in rotary kilns. Typically, a process for treatment involves heating to a temperature greater than 850°C or, if the waste contains more than 1 per cent of halogenated organic substances, to a temperature greater than 1 100°C, with a residence time greater than two seconds under conditions that ensure appropriate mixing. Dedicated hazardous waste incinerators are available in a number of configurations, including rotary kiln incinerators and static ovens (for liquids with low contamination). High-efficiency boilers and lightweight aggregate kilns are also used for the co-incineration of hazardous wastes.

6.3.1 Waste management in the major ship recycling countries

China has ratified the Stockholm convention but has registered for exemption for PFOS in among other firefighting foams. DNV GL has not identified that the revised Chinese National Catalogue of Hazardous Wastes has a specific category for PFOS. It is likely that no specific waste management requirements of PFOS has been implemented in Chinese legislation as of today.

Turkey has ratified the Stockholm convention and Turkey has prepared waste management legislation similar to waste regulations in the EU. Even though the legislation is in place, it is questionable whether the waste legislations have been implemented on the ground at the ship recycling facilities. One reason might be that only a fraction of vessels is delivered to a recycling facility with an IHM part 1, 2 and 3. The vessels that come with an IHM will in most cases not list PFOS because it is not required by the Hong Kong Convention. This does not necessarily mean that it is not present onboard, but merely that it has not been considered during preparation of the IHM.

No specific waste legislation, suggesting suitable downstream waste management, have been found for India, Bangladesh and Pakistan.

7 INTERNATIONAL TREATIES AND IMO

PFOS is regulated internationally by the Stockholm Convention and is applicable to ships flagged by a signatory to the Convention, but references to PFOS cannot be found in maritime legislation such as SOLAS and MARPOL. It should be noted that PFOS is regulated by the EU Ship Recycling Regulation, but only for vessels that fly the flag of a Member State. When and if the Hong Kong Convention enters into force, PFOS may be added to Appendix 1 materials, but it is still not ratified almost 9 years after adoption. The Stockholm Convention regulates amongst others, in addition to PFOS, polychlorinated biphenyls (PCBs) listed in Appendix 1, polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDE) polychlorinated naphthalenes (more than 3 chlorine atoms) and certain shortchain chlorinated paraffins (Alkanes, C10-C13, chloro) which all are listed in Appendix 2 of the Hong Kong Convention, hence the IMO have included many substances regulated under the Stockholm Convention, but not PFOS.

The EU Ship Recycling Regulation include PFOS and Hexabromocyclododecane (HBCDD) in addition to the substances mentioned above (listed in Appendix 2 of the Hong Kong Convention). HBCDD has been listed in Annex A of the Stockholm Convention since 2013. All ships flying the flag of a Member State shall be subject to a survey regime and carry on board a ship specific 'Inventory Certificate' issued by the administration or a RO authorised by it and supplemented by Part I of the IHM.

The Stockholm Convention foresees that waste containing, consisting of or contaminated with POPs should be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that it does not exhibit POPs characteristics. Where this does not represent the environmentally preferable option or where the POP content is low, waste shall be otherwise disposed of in an environmentally sound manner. Disposal operations that may lead to recovery or re-use of POPs are explicitly forbidden. With regard to shipment of wastes, relevant international rules, standards and guidelines, such as the 1989 Basel Convention on the Control of Trans-Boundary Movements of Hazardous Wastes and their Disposal, are to be taken into account.

The EU Ship Recycling Regulation provides measures to ensure environmentally sound waste disposal through its requirements for a ship recycling facility to be listed in the European List. Environmentally sound management may only be assumed to be in place if the ship recycling company can demonstrate that the waste management facility which receive the waste will be operated in accordance with human health and environmental protection standards that are broadly equivalent to relevant international and Union standards.

A parallel can be drawn between the situation of the Stockholm Convention and implementation onboard vessels, and the Montreal Protocol and implementation onboard vessels. During the 1980s, concern over air pollution, such as global warming and the depleting of the ozone layer, continued to grow, and in 1987 the Montreal Protocol on substances that Deplete the Ozone Layer was signed. The Montreal Protocol is an international environmental treaty, drawn up under the auspices of the United Nations, under which nations agreed to cut consumption and production of ozone-depleting substances including chlorofluorocarbons (CFCs) and halons. In 1992 in Copenhagen a Protocol was signed introducing accelerated phase-out dates for controlled substances, cutting short the use of transitional substances and the introduction of phase-out dates for HCFCs and methyl bromide. CFCs have been in widespread use since the 1950s as refrigerants, aerosol propellants, solvents, foam blowing agents and insulants. In shipping, CFCs are used to refrigerate ship and container cargo, insulate cargo holds and containers, air condition crew quarters and occupied areas and refrigerate domestic food storage compartments.

Halons, manufactured from CFCs, are effective fire extinguishers used in portable fire extinguishers and fixed fire prevention systems. When this first became an issue in the early 1990's, air pollution from vessels accounted for only a small minority of all such pollution. A paper submitted by Norway to the Marine Environment Protection Committee [MEPC] of the International Maritime Organization [IMO] in 1990 calculated amongst other that:

- Chlorofluorocarbons [CFC] emissions from vessels amounted to 3~6 million tonnes p.a, or about 1~3% of total global emissions
- Halon emissions from vessels amounted to 300~400 tonnes p.a, or about 10% of total global emissions

However, as land based industries became subject to regulation in this regard, their levels began to fall, making emissions from merchant vessels a growing percentage of the total. Because of this, legislation was required in the maritime sector. This started with IMO resolution A.719(17) in 1991 which eventually developed into a specific regulation in MARPOL Annex VI. Regulation 12 of Annex VI prohibits, among others, deliberate emissions of ozone depleting substances, which include halons and chlorofluorocarbons (CFCs). New installations containing ozone-depleting substances are prohibited on all ships. But new installations containing hydro-chlorofluorocarbons (HCFCs) are permitted until 1 January 2020. The requirements of Regulation 12 in MARPOL Annex VI are in accordance with the Montreal Protocol of 1987, as amended in London in 1990 (http://www.imo.org). On 16th September 2009, the Vienna Convention and the Montreal Protocol became the first treaties in the history of the United Nations to achieve universal ratification (http://ozone.unep.org/en/treaties-and-decisions).

The Montreal Protocol, Article 2 – 11 states: Notwithstanding the provisions contained in this Article and Articles 2A to 2I Parties may take more stringent measures than those required by this Article and Articles 2A to 2I. The European Union (EU) decided to follow this option by phasing out R-22 (and for EU flag ships) by January 1st 2010.

- After this date, R-22 cannot be produced or imported into EU.
- From Jan.1st 2010 until Jan.1st 2015 only reclaimed / recycled R-22 could be charged into systems onboard EU flag ships.
- After Jan. 1st 2015 R-22 cannot be charged into any system in EU, what-so-ever, being virgin, recovered, recycled or reclaimed.

Norway has, as EU, decided to follow the option for more stringent measures and included this in national legislation. This will also impact vessels operating under a non-EU or Norwegian flag on the Norwegian continental shelf, where the more stringent Norwegian laws will apply. For example, a rig owner operating under a flag where HCFC is allowed until 2020, cannot repair or refill an existing system with R-22, but must find alternative refrigerant gas to replace the existing gas onboard if the rig is in operation on the Norwegian continental shelf.

In 2015, 193 countries adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). As part of the United Nations family, IMO is actively working towards the 2030 Agenda for Sustainable Development and the associated SDGs. In addition to this, the UN Environment Assembly met in December 2017, under the slogan "*Towards a Pollution-Free Planet*", where the nations of the world will come together to declare strengthened political commitment for beating pollution. They will explore practical, policy and financial ways to protect human health and the environment from the impact of pollution to air, soils, seas and bodies. Protecting human health and the environment is the overarching and common goal of the Basel, Rotterdam, and Stockholm conventions. These legally binding instruments provide the internationally-agreed ground rules for countries to develop laws and frameworks ensuring the sound management of chemicals and waste.

8 CONCLUSIONS

This study has shown that approximately 17 000 ships has fixed firefighting foam tanks onboard, with volumes in the range from 400 litres to 18700 litres, containing PFOS, PFOA impurities and precursors, PFHxS or PFHxA or a mixture of these.

Almost 7 000 ships are very likely to have PFOS in the firefighting foam onboard. Approximately 5 000 ships are likely to have PFOS or traces of PFOS in their firefighting foam. For ships delivered after 2010, it is assumed that a very small percentage of vessels may have PFOS in firefighting foams from the date of delivery. It is presumed that possible replacement of foam will give an insignificant reduction in number of ships that may have firefighting foams containing PFOS, because even though tanks are thoroughly clean, PFOS-concentrations above the threshold level can occur. This is due to PFOS being a very strong surfactant, clinging to the surface of the tank and other infrastructure. It should be emphasized, however, that when replacing PFOS-containing firefighting foam, less PFOS will be emitted to the environment when the foam system is used for training or for actual firefighting.

After a production history of over half a century, PFOS and its precursors are now listed, PFOA and related precursors and PFHxS its salts and related compounds are being evaluated for listing, under the Stockholm Convention on Persistent Organic Chemicals. There have also been several national and regional regulatory and voluntary initiatives established to regulate PFOS, PFOA, PFHxS and some other PFAS, mostly in developed countries.

References to PFOS in maritime legislation such as SOLAS and MARPOL is absent, while PFOS is regulated by the EU ship recycling regulation, for vessels that fly the flag of a Member State. When and if the Hong Kong Convention enters in to force, PFOS may be added to Appendix 1 materials, but it has still not entered into force almost 9 years after adoption. Hence, it might be worthwhile to see if there are ways to implement the Stockholm Convention onboard vessels, both to restrict the use of listed substances, and to ensure safe and environmentally sound downstream waste management.

9 REFERENCES

1. Air Service Australia. Air services use of firefighting foam: http://www.airservicesaustralia.com/environment/firefightingfoam/

2. Avinor. Emmission to water and ground: https://avinor.no/en/corporate/community-and-environment/utslipp-til-vann-og-grunn/

3. Baduel, C., Paxman, C. J., Mueller, J.F., (2015). Perfluoroalkyl substances in a firefighting training ground (FTG), distribution and potential future release. Journal of Hazardous Materials, 296 (2015), 46-53

4. Basel Convention. General technical guidelines on the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (adopted by COP.12, May 2015).

5. Basel Convention. Technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF) (adopted by COP.12, May 2015).

6. Buck, R. C., Franklin, J., Berger, U., Conder, J. m., Cousins, I. T., Voogt, P., Jensen, A. A., Kannan, K., Mabury., S. A., Leeuwen, S. (2011). Perfluoroalkyl and Polyfluoroalkyl Substances in the Environment: Terminology, Classification, and Origins. Integrated Environmental Assessment and Management, 7 (4), 513-541

7. Danish Ministry of the Environment, Environmental Protection Agency, Short-chain Polyfluoroalkyl Substances (PFAS), A literature review of information on human health effects and environmental fate and effect aspects of short-chain PFAS, Environmental project No. 1707, 2015.

8. Darwin, R. L (2004). Estimated Quantities of Aqueous Film Forming Foam (AFFF) in the United States. Prepared for the Fire Fighting Foam Coalition.

9. Dr. Sthamer (2011). FOAM and Environment 27.01.2011/Gardermoen Airport. http://ctif.no/uploads/Vortrag%20-%20Foam%20and%20Environment%20-%20Avinor-Oslo%20-%2027.01.2011.pdf

10. Emerging contaminants (2016). PFOS and PFOA – Production – Use – Sources. Fact sheet: http://www.emergingcontaminants.eu/index.php/background-info/Factsheets-PFOS-intro/Factsheets-PFOS-production

11. EMSA's Best Practice Guidance on the Inventory of Hazardous Materials, IHM development and maintenance in the context of the EU Ship Recycling Regulation. Monitoring and enforcement in the context of the EU Ship Recycling Regulation (2016).

12. EMSA (2017). Study on the two hazardous substances (PFOS and HBCDD) included in the annexes of regulation (EU) 1257/2013 on ship recycling.

13. The European Chemicals Agency (ECHA) (2017). PACT – RMOA and hazard assessment activities. https://echa.europa.eu/pact

14. FFFC (2017). Fact Sheet on AFFF Fire Fighting Agents: https://docs.wixstatic.com/ugd/331cad_fa5766eb867b4a5080330ce96db195fa.pdf

15. The Fluoro Council. https://fluorocouncil.com/default.aspx

16. Herzke, D., Olsson, E., Posner, S. (2012). Perfluoroalkyl and polyfluoroalkyl substances (PFASs) in consumer products in Norway – A pilot study. Chemosphere 88 (2012), 980-987

17. IMO. Historical background MARPOL Annex VI: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Historic-Background-.aspx

18. KEMI (2015). Chemical Analysis of Selected Fire-fighting Foams on the Swedish Market 2014. PM 6/15

19. Martin, J. W., Asher, B. J., Beesoon, S., Benskin, J. P., & Ross, M. S. (2010). PFOS or PreFOS? Are perfluorooctane sulfonate precursors (PreFOS) important determinants of human and environmental perfluorooctane sulfonate (PFOS) exposure?. Journal of Environmental Monitoring, 12(11), 1979-2004.

20. Miljødirektoratet. Brannskumprodusent må kartlegge forurensning. http://www.miljodirektoratet.no/no/Nyheter/Nyheter/Old-klif/2012/April_2012/Brannskumprodusent_ma_kartlegge_forurensning/

21. Norwegian Pollution Control Authority (SFT) (2005). Kartlegging av PFOS i brannskum. TA-2139/2005. ISBN 82-7655-275-7. http://www.miljodirektoratet.no/old/klif/publikasjoner/kjemikalier/2139/ta2139.pdf

22. Moody, C. A., Field, J. (2000). Perfluorinated Surfactants and the Environmental Implication of Their Use in Fire-Fighting Foams. Environmental Science and Technology, 34 (18), 3864-3870

23. Paul, A. G., Jones, K. C., Sweetman, A. J., (2009). A First Global Production, Emission And Environmental Inventory For Perfluorooctane Sulfonate. Environmental Science and Technology, 2009 (43), 386-392

24. Place, B., Field, J. (2012). Identification of Novel Fluorochemicals in Aqueous Film-Forming Foams (AFFF) Used by the US Military. Environmental Science and Technology, 46 (13), 7120-7127.

25. Queensland Department of Environment and Heritage Protection (2016). Environmental Management of Firefighting Foam Policy Explanatory Notes Revision 2.

26. Reach helpdesk. http://www.reach-clp-biozid-helpdesk.de/en/REACH-en/SVHC-Roadmap-en/DE_RMOA-Liste-en/DE_Stoffliste-en.html

27. Scheringer, M., Trier, X., Cousins, I. T., Voogt, P, Fletcher, T., Wang, Z., Webster, T. F. (2014). Helsingør Statement on Poly and perfluorinated alkyl substances (PFASs). Chemosphere 114 (2014), 337-339

28. Seow, J. (2013). Fire Fighting Foams with Fluorochemicals – Environmental Review. Conservation Western Australia

29. SFT (2005). Survey of PFOS in firefighting foams. TA-2139/2005. ISBN 82-7655-275-7

30. SFT (2007). Survey of national sources, 2007: PFOA in Norway. TA-2354-2007.

31. Solberg (2004), press release: http://www.solbergfoam.com/News-Media.aspx?page=2

32. Swedavia (2015). Swedavias erfarenheter av brandsläckningsskum. Dialog om åtgärder mot högfluorerade ämnen i brandsläckningsskum 12 maj 2015, KEMI.

33. Tyco (2009). European Community Environment Ministry Ban on Fire Fighting Foams Containing PFOS. http://www.skum.com/HTML/NewsApplications/documents/PFOSletter1209.pdf

34. UNEP (2015). Proposal to list pentadecafluorooctanoic acid (CAS No: 335-67-1, PFOA, perfluorooctanoic acid), its salts and PFOA-related compounds in Annexes A, B and/or C to the Stockholm Convention on Persistent Organic Pollutants: http://chm.pops.int/Convention/POPsReviewCommittee/Chemicals/tabid/243/Default.aspx

35. UNEP (2017). Proposal to list perfluorohexane sulfonic acid (CAS No. 355-46-4, PFHxS), its salts and PFHxS-related compunds in Annexes A, B, and/or C to the Stockholm Convention on persisten Organic Pollutants: http://chm.pops.int/Convention/POPsReviewCommittee/Chemicals/tabid/243/Default.aspx

36. UNEP, Ozone Secretariat: http://ozone.unep.org/en/treaties-and-decisions

37. Unido, 2017. Guidance for the inventory of perfluorooctane sulfonic acid (PFOS) and related chemicals listed under the Stockholm Convention on Persistent Organic Pollutants.

38. United States Environmental Protection Agency Fact Sheet: 2010/2015 PFOA Stewardship Program https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program)

39. United States Environmental Protection Agency, press release: https://yosemite.epa.gov/opa/admpress.nsf/0/33aa946e6cb11f35852568e1005246b4

40. Vierke, L., Staude, C., Biegel-Engler, A., Drost, W., Schulte, C. (2012). Perfluorooctanoic acid (PFOA) – main Concerns and regulatory developements in Europe from an environmental point of view. Environmental Science Europe 24 (26).

41. Zhanyun Wang, Jamie C. DeWitt, Christopher P. Higgins, and Ian T. Cousins. A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? Environ. Sci. Technol. 2017, 51, 2508−2518.

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