

ANNEX XV RESTRICTION REPORT

PROPOSAL FOR A RESTRICTION (DRAFT)

SUBSTANCE NAME(S): Polyfluoroalkyl and perfluoroalkyl substances (PFAS) in firefighting foams

CONTACT DETAILS OF THE DOSSIER SUBMITTER:

VERSION NUMBER:

DATE:

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Overview - Problem Analysis Investigation Report

Grounds for the restriction proposal and possible issues identified

This Problem Analysis Investigation Report (PAIR) gives the status of the investigation to propose an Annex XV restriction on the placing on the market and use of PFAS in firefighting foams. The option of restricting in addition the manufacture of PFAS foam concentrates is also discussed. The report is intended to be a basis for discussion with the Commission on how to take forward this restriction proposal.

In July 2020, the Commission requested ECHA to prepare a restriction proposal in accordance with Article 69(1) of REACH of PFAS in firefighting foam and to cooperate with the authorities working on the broad restriction of PFAS¹ (hereafter referred as "universal PFAS restriction"). ECHA updated the Registry of Intentions and announced a planned submission date of 1st October 2021².

The present Annex XV report is largely based on study jointly contracted by the Commission and ECHA in 2019 on possible regulatory management options to address the risks of the risks of PFAS in firefighting foams in the EU³, hereafter referred to as Wood (2020). This study included extensive literature searches, stakeholder surveys and a workshop. However, comments received from stakeholders during the opinion-making process of the PFHxA restriction proposal⁴ and a call for evidence held to support the development of a universal PFAS restriction proposal by NL, DE, SE, DK and NO⁵ (which at the time included the use of these substances in firefighting foam) indicated that certain key elements of Wood (2020) might need to be revised, in particular the annual usage rate of foams and the total stock in the EU. On this basis, additional consultancy work was contracted by ECHA early 2021 to clarify a series of elements with stakeholders and based on literature review. The outcome of this work is expected in June 2021 and will be incorporated in the present report. Since these key input parameters affect several calculations and sections of the Annex XV report, significant review and update time is envisaged to take place after the new data is received.

Despite several stakeholder consultations, it is likely that some of the information sought for the analysis will not be available or will be of low quality (e.g. lack of supporting evidence, poor justification for representativeness, lack of specificity, large uncertainties, conflicting information). In the absence of further information from stakeholders, best estimates and robust assumptions will be generated using the information available, highlighting the limitations and uncertainties. Assumptions will be revised during opinion making if additional credible information become available. The necessary information to revise an assumption (i.e. that would be needed to be submitted during the consultation on the Annex XV report) could be clearly stated in the Annex XV report.

¹ https://echa.europa.eu/documents/10162/13641/request_echa_pfas_fff_en.pdf/aa089887-bc27-e642-747e-b935809075cc

² <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e1856e8ce6>

³ https://echa.europa.eu/documents/10162/28801697/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98

⁴ Restriction on undecafluorohexanoic acid (PFHxA), its salts and related substances available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

⁵ <https://www.reach-clp-biozid-helpdesk.de/SharedDocs/Meldungen/DE/REACH/2020-05-08-RMOA-PFAS.html>

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Hazard and concern

PFAS are persistent substances and most PFAS are also easily transported in the environment covering long distances away from the source of their release. These substances have been frequently observed to contaminate groundwater, surface water and soil. Remediating polluted sites is technically difficult and costly. If releases continue, they will continue to accumulate in the environment, drinking water and food.

Wood's study did not address in detail the hazard and risk of PFAS as this was initially planned to be developed by ECHA. In addition, considering the Commission's request to cooperate with the authorities working on the universal PFAS restriction, ECHA identified that the work performed by these authorities on the scope of substances identity, the hazard and risk could be used in ECHA's restriction proposal on PFAS in firefighting foams. This integration would benefit all parties by saving resources and experimenting the approach (sometimes termed 'ice-breaker') with a restriction dossier that would undergo the RAC-SEAC opinion-making ahead of the universal PFAS restriction. The five authorities would then be able to use the learnings from the opinion-making of ECHA's restriction proposal to adapt their own proposal prior to, or in the initial period after, its submission.

The main challenge with the proposed approach is the timing of ECHA's restriction proposal preparation for which final input from the authorities on the SID scope, hazard and risk would be needed by summer 2021. The authorities have shown commitment to the suggested approach and further discussions in June 2021 will take place to confirm it and the associated timeline. ECHA is providing precise information on timelines and deliverables (and formats) within a 'concept paper', that is currently being drafted. Should it not be possible to use the hazard approach of the universal restriction, this is likely to require additional work from ECHA (possibly using a consultant) to address this part of the Annex XV report. A key decision point over the next few weeks will be on whether to continue cooperation with the universal restriction or whether to invoke the contingency plan.

Emissions modelling

In terms of emission and exposure assessment Wood (2020) chose two identified PFAS substances to calculate and represent the overall emissions of PFAS to the environment (water, air, soil) based on the quantities of firefighting foams used per sector or type of use and emission parameters across the foam life cycle based on standard parameters or expert judgement. Due to the absence of specific annual usage rates for all sectors and types of use (especially training), the emission parameters are based on assumptions from the and might not represent the reality or could be challenged during the opinion-making process. The shares and amounts of PFAS foams (a) still used in training and (b) never used and sent to incineration when reaching expiry date are still unclear. These elements have an important impact on the emissions and the disposal costs under the restriction option where PFAS foams have to be disposed of at the end of the transitional period. The latest attempt to contact stakeholders (survey targeted on the users) has been initiated on 6 May 2021 to clarify these elements (deadline for response: 4 June 2021). In absence of more specific information, assumptions will be made based on the more generic information already available.

Also, the approach taken for the emission characterisation is simple and does not model complex fate aspects (e.g. flow across environmental compartments, degradation

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products, direct human exposure) This simple assessment has been chosen based on RAC and SEAC approach to consider emissions as a proxy for risks and impacts ('PBT/vPvB approach') and due to the complexity of modelling the fate of a very large number of PFAS substances This approach could also be challenged during the opinion-making process unless RAC agrees that PFAS should be considered as non-threshold and that releases should be minimised as per PBT/vPvB substances (see links to hazard/risk above) Independently of this issue, the emission estimation will model the variation of emissions per sector of use according to different transitional periods

Cost calculations

The cost calculations consider both costs and savings to industry These comprise price differences between PFAS and fluorine-free foams, higher quantities of fluorine-free foams needed to achieve the same level of fire-protection, savings in clean-up and incineration costs

The absence of clear information on some of the main input data affecting cost calculations, especially the amount of foam stocks in the EU and the cost of equipment cleaning (to achieve different concentration limits) and change in equipment to use alternatives, leads to large ranges of costs associated with the restriction options However, we are currently trying to collect more specific information which would allow narrowing down these cost ranges

The possibility to assess technical RMMs to contain releases for sectors where containment may be possible cannot be currently assessed from the cost perspective due to lack of data, however, we are currently collecting information on that as well

Summary of the restriction proposal

This Annex XV report describes a restriction proposal on the manufacture, use and placing on the market of PFAS in fire-fighting foams.

Commented [MD1]: To be confirmed.

Per- and polyfluoroalkyl substances (PFAS) are a large family of thousands of synthetic chemicals that are widely used throughout society and found in the environment. They all contain carbon-fluorine bonds, which are one of the strongest chemical bonds in organic chemistry. This means that they resist degradation when used and also in the environment. Most PFAS are also easily transported in the environment covering long distances away from the source of their release.

All PFAS are highly persistent in the environment. In fact, they are known to persist in the environment longer than any other man-made substance. As a consequence of this persistence, as long as PFAS continue to be released to the environment, humans and other species will be exposed to ever greater concentrations of PFAS. Even if all releases of PFAS would cease tomorrow, they would continue to be present in the environment, and humans, for generations to come. Their release and mobility in water and air causes contamination to groundwater and drinking water, which is difficult and costly to avoid. Certain PFAS are known to accumulate in the bodies of living things and cause toxic effects. Certain PFAS are toxic for reproduction and can harm the development of foetuses. Several PFAS have been demonstrated to cause cancer. Some PFAS are also suspected of interfering with the human endocrine (hormonal) system and testing in this area is ongoing. PFAS are released into the environment from direct and indirect sources, for example, from professional and industrial facilities using PFAS, during use of consumer products (e.g. cosmetics, ski waxes or clothing) and from food contact materials. Humans can be exposed to them every day at home, in their workplace and through the environment, for example, from the food they eat and drinking water⁶.

PFAS have been frequently observed to contaminate groundwater, surface water and soil. Cleaning up polluted sites is technically difficult and costly. If releases continue, they will continue to accumulate in the environment, drinking water and food.

Whilst some PFAS are subject to risk management (e.g. PFOS, PFOA) or will be subject to risk management in the future (e.g. C9-C14 PFCA, PFHxS, PFHxA), there is a lack of regulation for the PFAS as a whole, and of implementation or proven effectiveness of risk management measures to address the release of PFAS from the use of PFAS-based fire-fighting foams. Fluorinated fire-fighting foams are the cause of many cases of contamination in Europe, both of soil and drinking water (Wood, 2020). The most relevant technologies for the remediation of PFAS contamination from use of fire-fighting foams have also been identified (Wood, 2020). National regulation does not appear to be forthcoming and discrepancies across Member States could affect the functioning of the internal market. Since firefighting foams being traded over the borders and that it is not meaningful or possible to restrict them nationally due to internal market considerations, it is therefore concluded that a restriction on the placing on the market and the use of PFAS-containing fire-fighting foams at EU-level appears to be an appropriate option.

⁶ Source. ECHA website: <https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas>

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The **substance identities** of the PFAS currently used in firefighting foams are largely unknown due to manufacturer secrecy, claiming though that they mostly belong to the C6 chain length category. However, shorter chain structures have also been found from other information sources. Consequently, a restriction covering all PFAS would allow addressing all chain lengths and avoid regrettable substitution by shorter chain PFAS.

In terms of **market**, in the EU around 30 000 tonnes of firefighting foams are manufactured per year by around 25 manufacturers, 67% of this tonnage being PFAS-based foams (20 000 t/year). It is estimated that 60-70 Mio. EUR of revenues are generated from the sales of firefighting foams, with 25 % resulting from exports to non- EEA countries. Precise data on imports is missing but are estimated to be in the same order of magnitude as for exports.

These foams are used for fires involving flammable liquids ("class B fires") by a variety of sectors (oil/ (petro)chemical, municipal fire brigades, marine, airport, defence, ready for use products). By far, the largest sector of use being the oil and (petro)chemical (59% of tonnage).

The main function of PFAS contained in fire-fighting foam is to act as a surfactant, that is to form a film over the surface of a burning liquid in order to prevent flammable gases from being released from it as well as reigniting. This is a particularly relevant feature that enables applications in industrial fires - for example tank fires, where large quantities of flammable liquid are stored. They are used for training purposes and in a variety of fire incidents, from small fires to large tank fires, and can be applied both with mobile and stationary equipment.

The investigations made for the preparation of this restriction proposal show **that safer fluorine-free fire-fighting foams are generally available** and technically feasible and have been successfully used in most of the sectors⁷ identified. However, additional testing of alternatives foams and application methods for specific uses (in particular large storage tanks of flammable liquids and installations with different types of flammable liquids) appears to be required to ensure that fire safety is not compromised.

In order to maximise effectiveness while minimising potential adverse socio-economic impacts of such a restriction, it appears appropriate to **propose specific transition periods by application and user sector**, because of their differences in terms of the likelihood of emissions and implications of switching to alternative foams. It is concluded that training and testing and use by municipal fire services should be the highest priority for a rapid transition to fluorine-free foams. Users have suggested a longer transition period of up to 10 years may be needed for specific applications (notably large atmospheric storage tank fires) where further testing is required to determine the technical feasibility of alternatives, and where potential fire-safety risks from using alternatives may be higher. The chemicals/petrochemicals sector is the largest user sector, so in order to ensure effectiveness of a restriction in reducing PFAS-emissions, it seems appropriate that any longer transition period should be limited to the **most sensitive applications within this sector, which could be defined as the installations subject to the Seveso Directive on major accident hazards.** **For all other sectors, shorter transition periods are expected to be**

⁷ Oil/(petro)chemical industry, defence, marine, airports, municipal fire brigades, ready-to-use products

Commented [MD2]: Limiting the longer transitional period (or permit system) to the large atmospheric tanks like proposed in the PFHxA restriction might not be appropriate because other installations/sites with similar fire risks exist and do not necessarily involve such large tanks (e.g. companies with different type of flammable liquids, refineries), as stakeholders have commented in the PFHxA restriction consultations. I suggest to extend to installations/sites subject to the Seveso Directive. See also explanations in the box below.

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sufficient to ensure a transition to PFAS-free alternatives while having limited economic consequences.

Alternatives to PFAS foams have mostly been tested in small scale tests according to standards, with a limited number of flammable liquids. However, the results of recent tests show that fluorine-free foams behave differently to PFAS foams and show more variability of performance. This necessitates additional testing with other flammable liquids and fire scenarios such as large fires to ensure their effectiveness under the range of scenarios where they could be applied. Since large fire incidents are rare and large fire testing is costly, little experience has been gained until now on such challenging fire scenarios. For this reason, even though a fluorine-free foam may have passed tests according to recognised standards and already be in use in some installations, it is not currently possible to assume that it would perform equally well in all potential fire scenarios, such as in a large fire incident or involving specific flammable liquids.

An additional reason for the need for further testing is that it is not only the foam itself which is important to consider but the foam in combination with the application method (application system and application parameters) that are key in managing a fire adequately.

Consequently, determining whether a given fluorine-free foam is a suitable alternative to a PFAS containing foam in a specific real-life fire incident is not straightforward. This is the reason for proposing different transitional periods per sector or type of use, which would allow additional time for further testing and the adaptation of equipment and application methods.

Regarding the setting of an appropriate **concentration limit** for any remaining PFAS in foams and equipment that previously used PFAS-based fire-fighting foams, the costs of cleaning associated with the different concentration limits will be presented. Stakeholder input suggests that 0.1 mg/L (or 100 ppb) can be achieved with a relatively simple cleaning process (cost likely low but not quantified); such a limit would remove the vast majority of emissions. Lower thresholds are achievable with more complex and costly processes. For instance, achieving 1 ppb could cost around €12 300 per appliance according to one estimate, which could imply EU total costs in the order of €1 billion. However, setting a lower concentration threshold would lead to a relatively small additional reduction in PFAS emissions, compared to the overall reduction achieved by the restriction.

Commented [MD3]: Under further review.

Finally, the restriction proposal suggests an obligation to apply **fire management plans** and **best practice risk management measures** during and after the use of PFAS-based firefighting foam. This covers among others foam purchase, containment, treatment, proper disposal of foams and fire water run-off, use of personal protective equipment. These measures could provide relatively effective reduction of PFAS emissions and exposure of workers and professionals at relatively low cost during the transition periods when PFAS-based foams continue to be used.

The inclusion of PFOA, its salts and PFOA related compounds in Annex I of the POPs Regulation, following the listing under the Stockholm Convention, will lead, in the next few years, to a partial substitution of fire-fighting foams containing these substances. However, available information suggests that other PFASs would still be available to be used in the foams.

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Considering the concern raised by substituting firefighting foams containing PFOA with other fluorine-based ones, the increasing availability of fluorine-free alternatives and the conclusions of the ECHA and Commission's study (Wood, 2020), the present restriction proposal, if adopted, would lead to a reduction of PFAS released in the environment while maintaining the necessary fire protection among the sectors of use.

The below table summarises the main risk management options assessed, their emission reduction potential, cost and cost effectiveness.

Table 1: Summary of the risk management options assessed

RMO#	RMO description ⁸	Emission reduction profile and possible issues identified	Emission reduction (T/year)	Total cost (€/year)	Cost effectiveness (€/kg avoided releases)
1	Restriction on the placing on the market but use continued to be allowed until expiry date of the stocks	Progressive reduction of emissions. Could lead to stock piling and issues with emergency stock re-fill.			
2	Restriction on the placing on the market and use	Faster reduction of emissions than RMO#1. Defined substitution deadlines leading to strong incentive for investments in substitution. However, no flexibility for sectors/sites for which alternatives would appear unsuitable at the end of the transitional period			
3	Restriction on the manufacture, placing on the market and use	Similar reduction of emissions and issues as RMO#2, exports are banned as well			
4	Restriction on the manufacture, placing on the market and use with derogation mechanism via a permit system to which only	Slower reduction of emissions than the other RMOs since the largest user sector would have the possibility to request derogation for use. Even if risk			

Commented [MD4]: See section 2.3 on RMO for further details on these RMOs (still under development).

Commented [MD5]: Figures to be completed later

⁸ All the risk management options include transitional periods adapted to the different sectors of use or type of use, supplemented with the requirement to implement risk management measures minimising the emissions of PFAS in the environment.

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	Seveso sites would be eligible	management measures are implemented (containment and treatment), these are never 100% effective, especially in case of large fire incidents. Main advantage: allows taking into account site-specific constraints for implementing the substitution.			
5	Restriction for all uses unless adequate risk management measures are in place to minimise the emissions to the environment	RMO proposed based on the discussions on the PFHxA restriction. Main advantage: allows substitution if technically and economically feasible and continued use of PFAS foams where this is not feasible, to the condition that adequate containment and reduction of emissions is ensured. Incentive for industry to provide additional information on conditions of use. However, in practice, this is likely to be only applicable in certain sites being able to implement such strict RMMs. Even if risk management measures are implemented (containment and treatment), these are never 100% effective, especially in case of large fire incidents.			

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Specific transition periods are proposed per type of foam use and the sensitivity analysis depicts the emission reductions and costs associated with other transition periods.

The Dossier Submitter's proposed risk management option is **option 3** and is specified in detail in the below paragraph "Proposed restriction".

Commented [MD6]: Still to be confirmed, based on the additional data which we expect to receive from stakeholders.

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

- Restriction of use in training, testing, municipal brigades and portable extinguishers only, other uses allowed until suitable alternatives are found + mandatory collection and treatment of concentrates and fire waters with techniques maximising mineralisation + reporting to ECHA and periodic review of the restriction for update of derogations

Issues: marine and offshore uses where collection and destruction is not possible, administrative burden for ECHA, much weaker incentive for substitution leading to continued emissions in the environment during an unknown but probably long period

- Restriction of use in training, testing, municipal brigades and portable extinguishers only + mandatory collection and treatment of concentrates and fire waters with techniques maximising mineralisation + inclusion of all PFAS in REACH Annex XIV leading to AfAs for remaining uses

Issues: marine and offshore uses where collection and destruction is not possible; unlikely to have all PFAS included in the Candidate List and Authorisation List, AfA would encompass all types of PFAS uses, not only firefighting foams and AfA process unlikely to be able to judge on the need for PFAS foam with regard to fire safety such as major accidents dealt by the Seveso Directive requirements

- A tax per ton of PFAS placed on the market

Issues: if set high enough, the tax would encourage substitution for uses where feasible alternatives are available. However, levying this tax would require unanimity in the EU to be implemented. A relatively high tax would be needed to have an effect on the use of PFAS-based firefighting foams since the PFAS concentration in these foams is low (typically around 3%) and that fire-safety considerations are likely to have more weight than foam price considerations in the users' decisions to transition to fluorine-free alternatives. It would not be possible to establish the risk reduction capacity in terms of release reduction upfront when deciding on the level of tax. Furthermore, substantial effort would have to be taken to develop such taxing scheme. Because of these challenges and limitations, tax scheme is not considered appropriate risk management measure for the use of PFAS-based firefighting foams.

- Gradual limitation of the average concentration of PFAS used in the manufacture of firefighting foams placed on the market

Issues: in a given firefighting foam product it is highly unlikely that the concentration of PFAS could be reduced below its current levels while ensuring maintaining its functionality. Therefore, a reduction of the PFAS concentration should be looked as an average concentration over all firefighting foams (PFAS and fluorine-free) placed on the market. In other words, this RMO would be a gradual (i.e. over time) reduction of the tonnages of PFAS foams to be allowed to be placed on the market. In practice, this would mean that the available PFAS foams would progressively be used by the sectors needing them the most, the other users switching to fluorine-free alternatives. However, it would be difficult for authorities

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to determine which amounts of PFAS firefighting foams should be allowed to be placed on the market without compromising fire-safety. Furthermore, substantial effort would have to be taken to develop such a regulatory scheme. Because of these challenges and limitations, this is not considered appropriate risk management measure for the use of PFAS-based firefighting foams.

Proposed restriction

Brief title: Restriction on the manufacture, placing on the market and use of PFAS in firefighting foams

Column 1	Column 2
Per- and polyfluoroalkyl substances (PFAS) CAS No. various EC No. various Defined as any substance having at least two perfluorinated carbons with the formula $C_nF_{(2n+1)}$ with ($n \geq 2$) directly attached to any chemical group, as one of the structural elements.	<i>Exemptions for PFASs restricted under REACH or the POPs regulation:</i> This regulation does not apply to PFASs as defined in column 1 that are covered by REACH Annex XVII entries and the POPs regulation Annex I which apply to: - PFHxA, its salts and related substances (REACH) - C9-C14 PFCAs, their salts and related substances (REACH) - (3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)silanetriol and any of its mono-, di- or tri-O-(alkyl) derivatives (REACH?) - PFOS and its derivatives (POPs) - PFOA, its salts and related compounds (POPs) - Other?
	1. Shall not be placed on the market as substances on their own, as a constituent in other substances or in mixtures for use in firefighting foam concentrates after the transitional periods for the types and sectors of use specified in paragraphs 3 and 4 unless the concentration of total PFAS is less than 10mg/L⁹. 2. Shall not be manufactured six months after entry into force for export as substances on their own, as a constituent in other substances or in mixtures for use in firefighting foam concentrates unless the concentration of total PFAS is less than 10mg/L 3. Shall not be used in firefighting foam concentrates with concentrations above the ones mentioned in paragraph 1 for training and testing purposes (except testing during the development phase of new PFAS foams and testing of the firefighting systems for their function), irrespective of the sector of use: 18 months after entry into force;

Commented [MD8]: To be aligned with the universal PFAS restriction on wording.

Commented [MD7]: To be aligned with the universal PFAS restriction on wording.

Commented [MD9]: Need to determine which testing types to ban:

Definitions of "testing" by Eurofeu (comment 2983 in PFHxA restriction, page 12)

- Testing of foam agents during their development phase,
- testing of foam agents by users to evaluate products and/or their suitability on specific combustibles;
- testing of systems for their function (cannot be done using surrogates as also the properties of the foam generated by the system are pass/fail criterion);
- testing of correct proportioning of firefighting foam concentrates (can be done using surrogates simulating hydrodynamic properties).

If testing of foams during their development phase is banned this means that no new PFAS foams can be developed. This could be problematic for the oil/chemical industry. We might only ban the use of testing of the correct proportioning of firefighting foam concentrates which can be done using surrogates.

⁹ Or 10 000 ppb, or 0.001%

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Column 1	Column 2
	4. Without prejudice of paragraph 3 on training and testing, shall not be used for other types of uses in firefighting foam concentrates with concentrations above the ones mentioned in paragraph 1 with the following transitional periods per sector or type of use: a. Establishments covered by the Seveso Directive (tier 1 and tier 2): 10 years after entry into force b. Marine applications: 3 years after entry into force c. Municipal fire services, ready-to-use applications (e.g. portable fire extinguishers): 18 months after entry into force d. All other uses not covered by paragraphs (a), (c) and (d): 5 years after entry into force 5. Six months after entry into force, industrial and professional users of firefighting foam concentrates containing PFAS above the threshold indicated in paragraph 1 shall: a. only use these foams for fires involving flammable liquids (class B fires); b. establish a fire management plan for every site and type of foam use which would include a description of the procedure and reasons for the procurement of the specific fire-fighting foam concentrates, their storage, use, containment and treatment and the efforts made to search for PFAS-free alternatives. The fire management plan shall: (i) aim at reducing the use of PFAS foams to the minimum necessary while transitioning to PFAS-free foams, (ii) be reviewed annually and kept available for enforcement authorities; c. ensure the minimisation of emissions of PFAS in the environment and direct and indirect exposure to humans from all activities related to firefighting such as but not limited to: the use of foam concentrates, water-added foams, fire waters, mixtures used to clean the equipment containing PFAS firefighting foams, by applying sector best practices. The measures shall ensure: (i) an adequate protection of workers using PFAS firefighting foams (ii) the maximisation of the collection of the waste

Commented [MD10]: To be checked w th stakeholders if this is feasible. Otherwise, 5 years should be feasible and merged with the other types of uses under para d.

Commented [MD11]: Includes e.g.: Civil aviation, aerospace, defence, offshore oil, gas and chemical manufacturing or processing facilities (unless covered by paragraph a.), sectors with minor uses: hospitals, power plants, glass manufacturers, waste treatment facilities, food processing industry, metal processing, etc.
Note: Offshore platforms likely lead also to ~full release (like marine applications) however Equinor took 8 years to transition their off-shore platforms to fluorine-free foams. Experience having been gained since then, 5 years should be fine.

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Column 1	Column 2
	(iii) that the waste disposal uses methods shall be treated with techniques maximising the mineralisation of the PFAS substances to the extent feasible. For each event of foam use or leakage handling, proof of appropriate management and disposal of the foam concentrates, water-added foams and fire water should be documented and kept available for enforcement authorities. 6. From six month after entry into force onwards, firefighting foam concentrates containing PFAS above the indicated threshold which are held in stock and need to be disposed of shall be treated with techniques maximising the mineralisation of the PFAS substances. Proof of appropriate disposal should be documented and kept available for enforcement authorities.

Commented [MD12]: I suggest this wording instead of "minimisation of the emissions to PFAS in the environment" because incineration at t° <1100°C can lead to the emiss on of fluorinated gases w th powerful greenhouse effect. To see if the PFAS substance ID scope covers these substances or not. If yes, then the standard wording of minimisation can be used instead.

Commented [MD13]: Cfr. comment above.

Question to the Commission:

Are the proposed RMOs which will be assessed in more details clear and appropriate?

1. The problem identified

1.1. Hazard, exposure/emissions and risk

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

1.1.1.1. Overview

Polyfluoroalkyl and perfluoroalkyl substances (PFAS) is a broad term used to cover approximately 4 700 substances. Long chain ($\geq C8$) PFAS were used as surfactants specifically because of their potent water and oil repellence at low concentrations (Buck, 2011¹⁰). However, short chain PFAS are nowadays used since the phase out of the long chain substances. According to Eurofeu, PFAS used in firefighting foam technology presently exclusively are of the C6-type.¹¹

The main function of PFAS in fire-fighting foam is to act as a surfactant, that is to form a film over the surface of a burning liquid in order to prevent flammable gases from being released from it as well as reigniting. They are therefore used in fires involving flammable liquid (Class B fires¹²) across a range of sectors. The quantities of foam used by different sectors are discussed in the sub-section below. PFAS-based fire-fighting foams are used for fires in many different applications involving flammable liquids, and are used in equipment such as small fire extinguishers up to large tank fires. They can be applied with both mobile and stationary equipment and are also used in training and testing of equipment.

A large number of highly diverse PFAS substances have been identified as being used in fire-fighting foams, as follows:

- Unsubstituted¹³ long chain PFAS (see Section 1.1.1.2 and Annex B 1.1.1 and B 1.1.2)
- Unsubstituted short chain PFAS (see Section 1.1.1.3 and Annex B 1.1.3 and B 1.1.4)
- Substituted short and long chain PFAS (see Section 1.1.1.4 and Annex B 1.1.5)

¹⁰ Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., de Voogt, P., Jensen, A. A., Kannan, K., Mabury, S. A. and van Leeuwen, S. P. (2011), Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integr Environ Assess Manag*, 7: 513-541. doi:10.1002/ieam.258

¹¹ Eurofeu (2020), "Comments on the PFHxA-Restriction Proposal", comment #2983 to the PFHxA restriction proposal, available in the document "part 2" available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

¹² The European Standard Classification of Fires distinguishes between the following fires:

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

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

Class C – fires involving gases;

Class D – fires involving metals;

Class K – fires involving live electrical apparatus;

Class F – fires involving cooking oils.

¹³ PFAS substances with perfluorinated alkaline carbon chain that is connected to a sulfonic- or carboxylic acid head group, not further equipped with additional chemical groups.

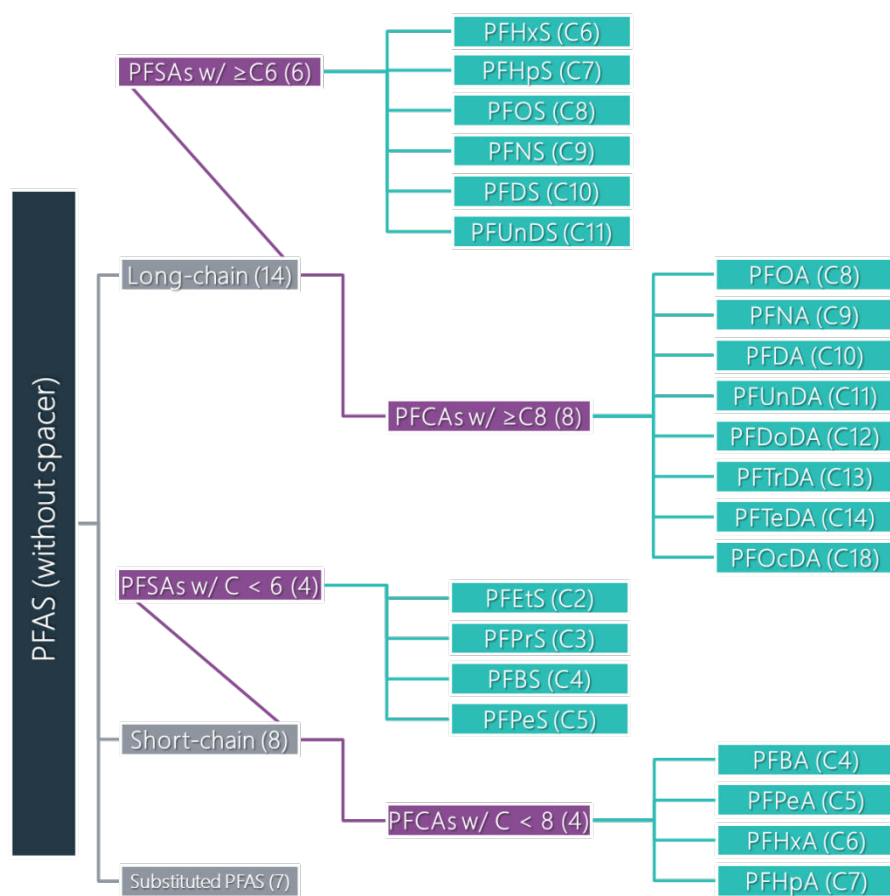
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- Fluorotelomers (see Section 1.1.1.5 and Annex B 1.1.6)
- Others (See Section 1.1.1.6 and Annex B 1.1.7)

Summary overviews of the long- and short-chain PFASs identified and of the fluorotelomer substances identified are provided in the figures below.

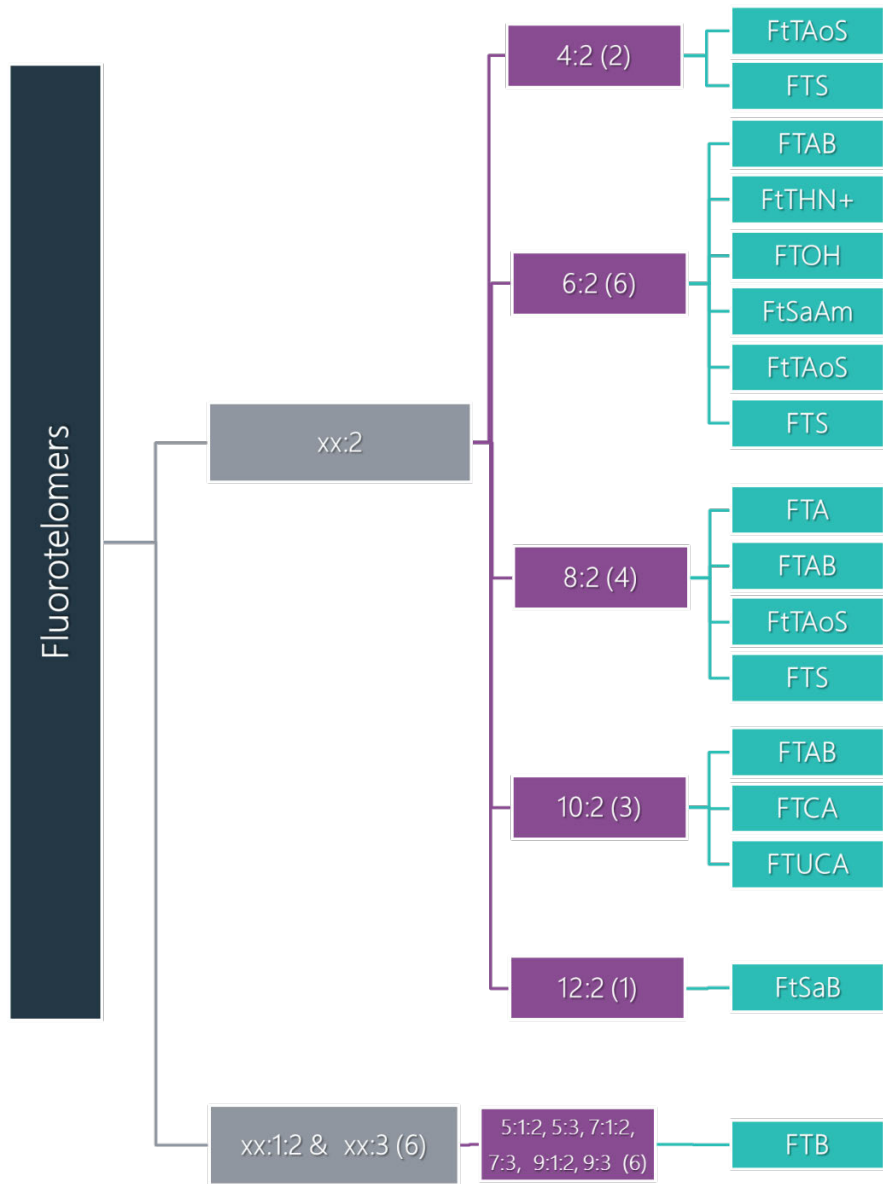
The figures below provide a hierarchical clustering of the substances that have been identified as being used in fire-fighting foams, including short-, long-chain and substituted PFAS (Figure 1 1) and also fluorotelomers (Figure 1 2).

Figure 1 1 Hierarchical clustering of the identified short-, long-chain and substituted PFAS substances



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Figure 1 2 Hierarchical clustering of identified fluorotelomers



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1.1.1.2. Long chain PFAS

The group of long chain PFAS consists of both perfluorosulfonic acids (PFSAs) with $C \geq 6$ (chemically defined as $C_nF_{2n+1}-SO_3H$)¹⁴ and perfluorocarboxylic acids (PFCAs) with $\geq C8$ ¹⁵ (chemically defined as $C_nF_{2n+1}-COOH$). The group of long chain PFAS (defined by OECD as perfluorosulfonic acids (PFSAs) with $C \geq 6$ and perfluorocarboxylic acids (PFCAs) with $\geq C8$) encompasses the following substances:

PFSAs with $\geq C6$ (see a full overview of these substances in Annex B 1.1.1)

- Perfluorohexane sulfonic acid (PFHxS) (C6)
- Perfluoroheptane sulfonic acid (PFHpS) (C7)
- Perfluorooctane sulfonic acid (PFOS) (C8)
- Perfluorononane sulfonic acid (PFNS) (C9)
- Perfluorodecane sulfonic acid (PFDS) (C10)
- Perfluoroundecane sulfonic acid (PFUnDS) (C11)

PFCAs with $\geq C8$ (see a full overview of these substances in Annex B 1.1.2)

- Perfluorooctanoic acid (PFOA) (C8)
- Perfluorononanoic acid (PFNA) (C9)
- Perfluorodecanoic acid (PFDA) (C10)
- Perfluoroundecanoic acid (PFUnDA) (C11)
- Perfluorododecanoic acid (PFDoDA) (C12)
- Perfluorotridecanoic acid (PFTTrDA) (C13)
- Perfluorotetradecanoic acid (PFTeDA) (C14)
- Perfluorostearic acid (PFOcDA) (C18)

1.1.1.3. Short chain PFAS

Short chain PFAS identified include sulfonic acids and carboxylic acids:

- PFSAs with C2-C5 (see Annex B 1.1.3)
 - ▶ Perfluoroethane sulfonic acid (PFEtS) (C2)
 - ▶ Perfluoropropane sulfonic acid (PFPrS) (C3)
 - ▶ Perfluorobutanesulfonic acid (PFBS) (C4)

¹⁴ The PFSAs and PFCAs identified as used in FFFs are covered by the general classification of per- and polyfluoroalkyl substances (PFASs) by the OECD.

¹⁵ C8 covers in this case perfluoroalkylcarbons as well as the single carbon belonging to the acid group.

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- ▶ Perfluoropentane sulfonic acid (PFPeS) (C5)
- PFCAs with C4-C6 (see Annex B 1.1.4)
 - ▶ Perfluoro-n-butanoic acid (PFBA) (C4)
 - ▶ Perfluoropentanoic acid (PFPeA) (C5)
 - ▶ Perfluorohexanoic acid (PFHxA) (C6)
 - ▶ Perfluoroheptanoic acid (PFHpA) (C7)

1.1.1.4. Derivates of perfluoroalkyl sulfonic PFAS (also PASF-based substances)

All the named substances above are characterised by a perfluorinated alkaline carbon chain that is connected to a sulfonic- or carboxylic acid head group. In other PFAS substances, this head group is also equipped with additional chemical groups. These other substances form the group derivates of perfluoroalkyl sulfonic PFAS, also called perfluoroalkane sulfonyl fluoride substances (PASF), as their synthesis is based on perfluoroalkane sulfonyl fluoride. This can be for example an amide (sometimes methylated or ethylated). The chemical formulae of this group can be summarised as:

- Perfluoroalkane sulfonyl fluoride (PASF) = $C_nF_{2n+1}SO_2F$
- PASF-based derivatives = $C_nF_{2n+1}SO_2-R$, where R = NH, $NHCH_2CH_2OH$, etc.

However, in most cases, these substances were not found when the actual foam was tested but rather when environmental samples were tested. In addition, some of the substances are also known to be environmental transformation products. Other substances are raw materials for surfactant and surface protection products (EtFOSE and N-MeFOSe) (Buck et al. 2011). In this sub group, the following substances were found:

- Perfluoroalkyl sulfonamido amines (PFOSaAm);
- C7-FASA – Perfluoroheptane sulfonamidoethanol (PFHpSA);
- C8-PFSiA (PFOSI);
- N-Ethyl perfluorooctane sulfonamidoacetic acid (EtFOSAA);
- N-Methyl perfluorooctane sulfonamidoacetic acid (EtFOSE);
- N-Methylperfluorobutanesulfonamide (FBSA);
- Perfluorooctane sulfonamide (FOSA);
- Perfluorooctane sulfonamido acetic acid (FOSAA);
- Perfluorooctane sulfonamidoethanol (FOSE);
- N-methyl perfluorooctanesulfonamidoacetic acid (N-MeFOSA);
- N-Methyl perfluorooctane sulfonamidoethanol (N-MeFOSE);
- Perfluoroalkyl sulfonamido amines (PFBSaAm);
- N-[3-(Dimethyloxidoamino)propyl] -3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluor-1-octanesulfonamid; and
- Carboxymethyl)dimethyl [3- (gamma-omega-perfluor-1-C6-14-Alkansulfonamid)propyl)ammonium.

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A full overview of the substituted short and long chain PFAS identified is provided in Annex B 1.1.5.

1.1.1.5. Fluorotelomers

Fluorotelomers are defined by having an additional non-fluorinated spacer between the perfluorinated alkyl chain and the charged head group (denoted as number of perfluorinated carbons: number of non-fluorinated carbons). The most known homologues of this subgroup are those that have a two carbon atom spacer (defined as $C_nF_{2n+1}-C_2H_4-R$)¹⁶.

Fluorotelomers cover a wide range of positively/negatively charged head groups or combinations of those. Most of the fully identified substances, exhibit the xx:2 structure, where two non-fluorinated carbon atoms are inserted between the perfluorinated carbon chain and the head group. However, in the case of fluorotelomer betaines also xx:1:2 and xx:3 are found. In the latter case, three non-fluorinated carbon atoms are inserted between the perfluorinated carbon chain and the head group. In the case of the xx:1:2 substances, an additional fluorinated carbon is inserted between the perfluorinated alkyl chain and the non-fluorinated spacer.

Based on the manufacturing dates that are cited in the respective publications, it can be assumed that the use of fluorotelomers in fire-fighting foams began later than the use of traditional PFAS substances without a non-fluorinated spacer.

The following head groups have been identified:

- Alkylbetaine (AB);
- Betaine (B);
- Carboxylic acid (CA);
- Hydroxy (OH);
- Thioamido sulfonates (TAoS);
- Unsaturated carboxylic acid (UCA);
- Sulfonamido betaines (SaB);
- Sulfonamide amine (SaAm); and
- Thio hydroxy ammonium (THN+).

A full overview of the fluorotelomer substances identified is provided in Annex B 1.1.6.

¹⁶ This corresponds with the general classification of per- and polyfluoroalkyl substances (PFASs) by the OECD, however fluorotelomers used in FFFs have also been identified with a spacer of three non fluorinated carbon atoms (for example 7:3 FTB), as well as fluorotelomers with a non-fluorinated and an additional single-fluorinated carbon.

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1.1.1.6. Other PFAS substances

In some cases, perfluorinated substances that do not belong to any of the named groups (long-/short-chain PFAS, fluorotelomers, and derivatives of perfluoroalkyl sulfonic PFAS) have been identified ('others').

The identified substances grouped under the term "others" show diverse chemical structures. A full overview of the chemical substances attributed to 'other' is provided in Annex B 1.1.7.

The only feature that is common to all of them is a perfluorinated substructure. The substances include:

- Ammonium 2,2,3 trifluor-3-(1,1,2,2,3,3-hexafluoro-3-trifluoromethoxypropoxy), propionate
- Dodecafluoro-2-methylpentan-3-one
- Poly(1,1,2,2-tetrafluoro-1,2-ethanediyl), α -fluoro- ω -2-[3-((carboxylatomethyl) dimethylammonio)propylaminosulfonyl]ethyl-
- Thiols, C8-20, gamma-omega-perfluoro, telomers with acrylamide
- Sodium p-perfluorooxynonene sulfonate
- Bis(trifluorovinyl)ether

However, in analogy to the perfluorinated ethers like ADONA ($C_nF_{2n+1}-O-C_mF_{2m+1}$), the substance Dodecafluoro-2-methylpentan-3-one (a ketone) could be defined by $C_nF_{2n+1}-CO-C_mF_{2m+1}$.

1.1.1.7. Substance identity restriction scope

Any regulatory action on chemical substances/substance groups relies on a precise chemical identification. In the following the identified PFAS-substances have been checked to confirm whether they are covered by the general classification of per- and polyfluoroalkyl substances (PFASs) by the OECD, which itself is based on the commonly agreed terminology for nomenclature of PFASs (Buck et al. 2011).

In the case of the PFCAs, chemically defined as $C_nF_{2n+1}-COOH$, the substances identified in this task, AFFF-related PFAS-substances, would be covered. This is also true for the sulfonic homologues (PFSA, defined as $C_nF_{2n+1}-SO_3H$). Fluorotelomers-based substances are chemically defined by having a non-perfluorinated spacer between the perfluorinated carbon chain and a polar head group. The most known homologues of this subgroup are those that have a two carbon atom spacer (defined as $C_nF_{2n+1}-C_2H_4-R$). This definition is also given in the OECD report ("Working towards a global emission inventory of PFASs: focus on PFCAS - status quo and the way forward"). In this task, multiple substances belonging to this group were identified, varying in the perfluorinated chain length. However, homologues with a spacer of three non fluorinated carbon atoms (for example 7:3 FTB) were also identified, thus the definition would need to be enlarged to $C_nF_{2n+1}-C_mH_{m+1}-R$, so that substance with a variable chain length could be included. In addition fluorotelomers with a non-fluorinated and an additional single-fluorinated carbon were identified (for example 7:1:2 FTB). In order to include such substances, the chemical definition for these homologues would need to be $(C_nF_{2n+1}-CHF-C_mH_{m+1}-R)$.

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The derivatives of PFSA substances are chemically defined by having an additional chemical moiety connected to the sulfonic headgroup ($C_nF_{2n+1}-SO_2-R$). All of the identified substances identified in this task would be covered by this definition.

The identified substances grouped under the term "others" show diverse chemical structures. The only feature that is common to all of them is a perfluorinated substructure. However, in analogy to the perfluorinated ethers like ADONA ($C_nF_{2n+1}-O-C_mF_{2m+1}$), the substance Dodecafluoro-2-methylpentan-3-one (a ketone) could be defined by $C_nF_{2n+1}-CO-C_mF_{2m+1}$.

The following table summarises the named PFAS classifications, the generalised chemical structures, and the minimal number of carbon atoms of AFFF-related PFAS substances. It is observable, that the common sub unit is a perfluorinated ethyl-group ($-C_2F_4-$ or $-C_2F_5$)¹⁷. Based on that, the definition that would be needed to be to cover the all relevant AFFF-related PFAS substances would be based on these particular $-C_2F_4-$ or C_2F_5 -sub groups.

Commented [MD14]: To be updated based on the Universal PFAS restriction SID scope.

Table 1.1 Overview of the PFAS classification, generalised chemical structures, and minimal number of C-atoms of substances that were identified as being used in AFFF

PFAS classification (Buck et al. 2011)	Generalised chemical structure	Minimal number of C-atoms as identified in AFFF
PFCAs	$C_nF_{2n+1}-COOH$	4
PFSAs I	$C_nF_{2n+1}-SO_3H$	2
PFSAs II	$C_nF_{2n+1}-SO_2-R$	4
Fluorotelomer-based substances I	$C_nF_{2n+1}-C_2H_4-R$	4
Fluorotelomer-based substances II	$C_nF_{2n+1}-C_mH_{m+1}-R$	4
Fluorotelomer-based substances III	$C_nF_{2n+1}-CHF-C_mH_{m+1}-R$	4
Perfluoroalkyl ether-based substances	$C_nF_{2n+1}-O-C_mF_{2m+1}$	2
Perfluoroalkyl ether-based substances	$C_nF_{2n+1}-CO-C_mF_{2m+1}$	2

In the following, a proposal for the definition in the form of substance identity, that could be used for a potential restriction, is made. For this, in the following table, the definition of PFOA as stated in the restriction (Entry 68 to Annex XVII to REACH) and a draft version of the possible definition for the restriction on PFAS-substances found in AFFF is shown. In addition, the definition in the "Information Document accompanying the "Call for evidence

¹⁷ $-C_2F_4-$ if incorporated in the chemical structure of the PFAS substance or $-C_2F_5$ when attached terminaly to the structure.

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supporting an analysis of restriction options for the PFAS group of substances (fluorinated substance(s))” as published in the context of the RMOA has been used.

Table 1.2 Comparison of the substance identification as in the PFOA restriction and a proposal made for the PFAS-substances in AFFF.

Perfluorooctanoic acid (PFOA) CAS No. 335-67-1 EC No. 206-397-9 and its salts. Any related substance (including its salts and polymers) having a linear or branched perfluoroheptyl group with the formula C_7F_{15}- directly attached to another carbon atom, as one of the structural elements. Any related substance (including its salts and polymers) having a linear or branched perfluorooctyl group with the formula C_8F_{17}- as one of the structural elements. The following substances are excluded from this designation: - $C_8F_{17}-X$, where $X = F, Cl, Br$. - $C_8F_{17}-C(=O)OH$, $C_8F_{17}-C(=O)O-X'$ or $C_8F_{17}-CF_2-X'$ (where $X' =$ any group, including salts).	Per- and polyfluoroalkyl substances (PFAS) CAS No. various EC No. various Any substance having at least two perfluorinated carbons with the formula $C_nF_{(2n+1)}$- ($n \geq 2$) directly attached to any chemical group, as one of the structural elements. [This is a provisional definition that would need to be tested in terms of its implications as part of the consultation on any future restriction proposal, and taking into account the conclusions of the PFAS working group.]
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Commented [MD15]: To be updated with the Universal PFAS restriction on SID scope.

In the following, the proposed definition is discussed in the context of whether it is comprehensive enough to avoid any existing or new PFAS being used in fire-fighting foams. For this the publicly available ECHA database has been checked using its advanced search feature based on structural elements.

Based on the proposed definition, any PFAS substance that contains $-C_nF_{2n+1}$ ($n \geq 2$) or $-C_nF_{n+1}$ ($n \geq 2$) as one of the structural elements would be covered. Substances with only one $-CF_3$ moiety would not be covered; however in this project no PFAS-substance with only a single- CF_3 moiety has been identified. In addition, this group is used, for example, in certain drugs and pigments.

A fluorine to chlorine replacement is for example found in F-53B (6:2 chlorinated polyfluorinated ether sulfonate), a novel mist suppressant used as a replacement in metal plating (mainly in China see Du et al., 2016). However, based on the entire structure this substance would also be covered by the definition proposed above.

1-Chloro-1,2,2,2-tetrafluoroethane (HCFC-124, CAS No 2837-89-0) is a substance used in refrigerants as replacements for "older" chlorofluorocarbons. HCFC-124 is also used in gaseous fire suppression systems as a replacement for bromochlorocarbons. This particular substance would be not covered by the definition; however its potential usage in AFFF is questionable as it is gaseous. A search for this sub structure ($-CClF_3$ or $(Cl)C(F)(F)F$) gave nine hits. A search for bromine $(Br)C(F)(F)F$ resulted in three hits. The limited amount of hits, does, in a first approximation, show how many substances would not be covered by

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a possible restriction as elaborated above. However, the data is limited to the information publicly available in the ECHA database.

Also a replacement of fluorine atoms by hydrogen is observed in some substances (fluorotelomers). However, the fluorotelomers in this project would all be covered. An additional search in ECHA based on the -CHF-CF₃¹⁸ substructure gave 15 hits.

Taken together, the proposed definition is very broad and should prevent existing or new PFAS being used in fire-fighting foams. However, when fluorine is replaced by, for example, chlorine, bromine or hydrogen, the resulting substances would not be covered.

It should be noted that this definition has been developed specifically in the context of fire fighting foams. This does not imply that it would be an appropriate definition for any other possible restriction on PFAS in other uses.

1.1.2. Justification for grouping

Due to the large number of PFAS chemicals (in general, but also specifically those used in fire-fighting foams), a substance-by-substance risk assessment and risk management approach is not considered to efficiently prevent risks to the environment and human health from a single PFAS or mixtures of them. While the specific hazards of individual PFAS can vary, they are all subject to some important common concerns. Notably, all PFAS either are, or degrade to, persistent chemicals. These persistent chemicals may accumulate in humans, animals and the environment, and have been shown to be ubiquitous in the environment and human bodies. Taking precautionary risk management actions for groups of chemicals and promoting the use of chemicals that are 'safe-and-circular-by-design' could help to limit future pollution¹⁹ while avoiding so-called regrettable substitution.

Commented [SP16]: Need to check with Universal restrict on

1.1.3. Classification and labelling

To be completed later based on the hazard/concern paper

Commented [MD17]: To be completed later based on the hazard/concern work from the Universal PFAS restrict on.

1.1.4. Hazard assessment

High level comments on the hazards associated with PFAS substances are provided here, in order to provide context on the need for action at the EU level. Further discussion on the hazards of the non-fluorinated alternatives is provided in Annex B, Section B.5.

Commented [MD18]: To be completed later based on the hazard/concern work from the Universal PFAS restrict on.

PFAS is a broad term used to cover approximately 4,700 specific chemical species²⁰ which have a wide range of uses. These uses are principally based around the carbon-fluorine bond which is particularly strong and offers physical properties that include high water and

¹⁸ SMILES (C(F)C(F)(F)F)

¹⁹ See for instance: <https://www.eea.europa.eu/themes/human/chemicals/emerging-chemical-risks-in-europe>

²⁰ OECD, 2018, PFAS database, toward a new comprehensive global database of per and polyfluoroalkyl substances.

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oil repellence²¹. The same properties mean that many PFAS substances are also highly mobile (within the natural environment) and highly persistent (see Appendix 3 of the underlying study²²). This can create issues where PFAS substances emitted to the environment reach and contaminate important resources such as groundwater²³. There is evidence to suggest that exposure to PFAS can lead to adverse health effects in humans (by eating or drinking food or water contaminated by PFAS). In particular the US EPA²⁴ highlight studies that indicate the longer chain (C8 PFAS) species PFOS and PFOA can cause reproductive and developmental, liver and kidney, and immunological effects on laboratory animals. Furthermore, both chemicals have caused tumours in animal studies. Their use is already restricted in the EU and elsewhere. Some short-chain PFAS (PFHxS, PFBS, [HFPO-DA](#)) have also been listed as SVHCs, based on there being an equivalent level of concern to the named groups of chemicals under the authorisation provisions under REACH (carcinogens, mutagens and reprotoxicants (CMRs) and persistent, bioaccumulative and toxic/very persistent and very bioaccumulative (PBTs/vPvBs) chemicals).

The Nordic Council of Ministers²⁵ commented that the annual health-impacts within an EEA exposure study (from all uses of PFAS, not only fire-fighting foams) was estimated at €52-84 billion. This gives an indication of the scale of the issue and magnitude of the potential impacts from the environmental build-up of PFAS. The same study describes remediation costs associated with contamination from PFAS at European sites ranging from several hundred thousand up to €40 million with one high-cost example for the Dusseldorf Airport, Germany estimating a total remediation cost of up to €100 million.

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

1.1.5. Exposure assessment

Based on an extrapolation of data provided by Eurofeu (see Annex A for more details) it is estimated that **around 20,000 tonnes of PFAS-based fire-fighting foams are sold in the EU per year**. Of these, about 12,000 tonnes are estimated to be employed in fixed

²¹ Buck et al, 2011, 'Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification and origins', Integrated environmental assessment and management vol 7 issue 4.

²² Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

²³ E.g. EFSA, 2012. Perfluoroalkylated substances in food: occurrence and dietary exposure. EFSA J. 10, 2743. Available at: <https://www.efsa.europa.eu/efsajournal/pub/2743>; Hu et al. 2016 Detection of Poly- and Perfluoroalkyl Substances (PFASs) in U.S. Drinking Water Linked to Industrial Sites, Military Fire Training Areas, and Wastewater Treatment Plants, Environ. Sci. Technol. Lett. 2016, 3, 10, 344-350; Hurley et al, 2016 Preliminary Associations between the Detection of Perfluoroalkyl Acids (PFAAs) in Drinking Water and Serum Concentrations in a Sample of California Women, Environ. Sci. Technol. Lett. 2016, 3, 7, 264-269; Ingelido et al, 2018, Environment International, Volume 110, January 2018, Pages 149-159

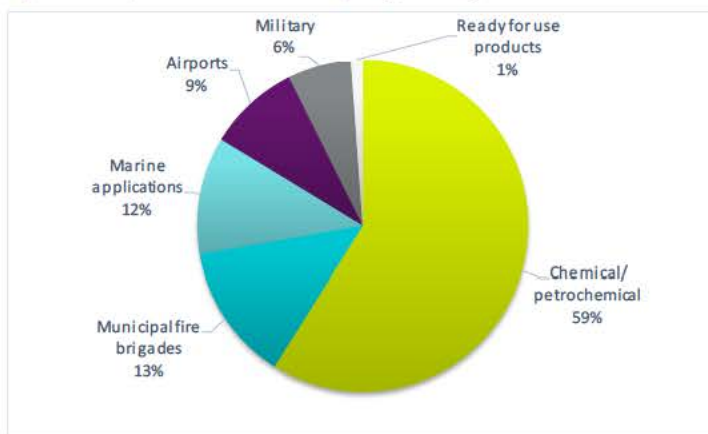
²⁴ US EPA, 2019, 'Basic information on PFAS', <https://www.epa.gov/pfas/basic-information-pfas>

²⁵ Nordic Council of Ministers, 2019, 'The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS', <http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

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systems and 8,000 in mobile systems²⁶. The split by sector is detailed in Figure 1.3 below. This shows that chemical/petrochemical is by far the largest user sector (59%), but municipal fire brigades, marine applications, airports and military applications also account for significant volumes. Ready-for-use products only account for a very small share of PFAS-based foams according to this data. The majority of this category are fire extinguishers, although not all foam fire extinguishers use ready-for-use foams (according to personal communications with Eurofeu). The annual tonnage of PFAS-based fire-fighting foam used in all extinguishers in the EU has been estimated at 360-675 tonnes (not counting the water that foam concentrates are mixed with in the extinguishers before/during use).

Figure 1.3 Split of PFAS-based fire-fighting foams by sector



Source: Data provided to the authors by Eurofeu.

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

Using a source-flow model and various assumptions that are outlined in Annex B, Section B.9., emission estimates have been developed to provide an illustrative assessment to help better understand the material flow and key emission compartments of fire-fighting foams.

The emission model developed in Section B.9. estimated that 26% of the two modelled example PFAS surfactants used in fire-fighting foams are released to the environment. Considering an average annual use of 18,000 tonnes of PFAS-based fire-fighting foams

Commented [MD19]: To be updated based on newer figures.

²⁶ All these figures have been extrapolated from the original values provided by Eurofeu, which covered approximately 70% of the market. The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split.

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and an average concentration of fluorosurfactants of 2.5%, **an annual emission of 117 tonnes of PFAS in the environment is calculated**. The table below summarises the results of the emissions calculations with different assumptions.

Table E.3 **Estimate of total PFAS emissions from fire-fighting foams**

	Tonnes of foams used per year	Concentration of PFAS surfactants in foams	Share of PFAS surfactants released into the environment	Tonnes of PFAS released
Low	14,000 t	2%	13%	36 t
Best	18,000 t	2.50%	26%	117 t
High	20,000 t	3%	39%	234 t

Sources: Annex A and Annex B (Section B.9.)

The source-flow model has been used to produce emission estimates for 10 unique non-fluorinated substances (hydrocarbons and detergents); as well as two PFAS-based substances. It highlights that fresh surface water and soil are the key receiving environmental compartments. Regarding non-fluorinated substances, live incidents are the major point of release, while for PFAS the waste phase is the key life-cycle stage for emissions, primarily from losses associated with releases at WWTPs.

Regarding the emissions by environmental compartment, it should be noted that while the non-fluorinated fire-fighting foams make up approximately one third of the market, the volumes of alternative surfactants can be greater than their PFAS counterparts due to greater concentrations within the product itself, potentially leading to higher emissions of the non-fluorinated alternatives. However, it is important to recognise that emission alone is not an indicator of impact, and the degradation rates, potential for bioaccumulation, and harmful effects also need to be considered (as discussed in the previous section 1.1.4 and in more detail in Annex B.5).

Regarding the emissions by life cycle stage, it should be noted that the major use of fire-fighting foams is for training purposes. During training exercises, aside from marine applications, it is assumed that the efficacy of bunding²⁷ and/or other control measures is relatively good. This means much of the fire-fighting concentrate within runoff is contained and sent for final destruction primarily within wastewater treatment plants (WWTPs) on-site or off-site.

For the non-fluorinated alternatives, the effectiveness of WWTPs is relatively good, minimising the emission which is split between surface water and soil. Because WWTPs are more effective in irreversibly destroying the named non-fluorinated substances, their use in training where run-off can be contained and treated leads to relatively low releases to the environment. This increases the relative importance of live incidents – where there is a direct release without treatment. For the PFAS-based substances, WWTPs is expected to be ineffective at treating PFAS, meaning direct release to surface water / soil depending on the partition coefficient. Waste is thus the most important life-cycle stage for the PFAS substances (see details in Annex B, section B.9.3).

²⁷ The use of retaining walls to contain fire-water run-off.

Commented [MD20]: This number will have to be recalculated based on the new data expected from industry (especially the annual usage rate per sectors and amount of stock). However, the logic of the emission model would remain the same.

@ [redacted] can you look at this model (see Excel sheets further below) if you think it is correct and sufficient for the purpose of the restriction? (actually two related models: (1) "business as usual" scenario, i.e. without restriction and (2) restriction with different sub-scenarios and different transitional periods per type of use.

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1.1.6. Risk characterisation

tbc]

Commented [MD22]: To assess if this will be assessed or if only emissions will be characterised.

Commented [PJ23R22]: Risk characterisation anyways needed, also in case of non-threshold case-by-case assessment.

1.2. Justification for an EU wide restriction measure

Section 1.1.4 has illustrated that there are concerns associated with PFAS. Some PFAS have been shown to cause reproductive and developmental, liver and kidney, and immunological effects as well as tumours in animal studies. Many PFAS are highly mobile, highly persistent, and have the potential to accumulate within the environment and living organisms. The assessed non-fluorinated alternatives' persistence is considerably lower than PFAS.

Section 1.1.5 has shown that, while in some user sectors PFAS-based foams have been increasingly replaced by fluorine-free alternatives and industry best practice guidance recommends not using PFAS-based foams in training and testing, some 20,000 tonnes of PFAS-based fire-fighting foams are still used annually in the EU in applications involving flammable liquid fires (Class B fires), including testing and training²⁸. This use leads to releases to the environment, with fresh surface water and soil being the key receiving environmental compartments. For non-fluorinated substances, live incidents are the major point of release, while for PFAS the waste phase is the key life-cycle stage for emissions, primarily from losses associated with releases at WWTPs. Some PFAS were shown to be ubiquitous contaminants, for instance in arctic wildlife²⁹.

The use of certain PFAS substances has been regulated in the past. This has led to the replacement of the regulated (e.g. long-chain) PFAS with fluorine-free alternatives in some cases, but also other PFAS substances (e.g. short-chain PFAS), as illustrated by the fact that the majority of fire-fighting foams used are still PFAS-based. Concerns have continued that shorter chain PFAS substances are also mobile (if not more mobile) than $\geq C8$ substances and are highly persistent, albeit with potentially lower bioaccumulation³⁰. Some (PFHxS, PFBS, HFPO-DA) have also been listed as SVHCs, based on there being an equivalent concern to the named groups of chemicals under the authorisation provisions under REACH (carcinogens, mutagens and reprotoxicants (CMRs) and persistent, bioaccumulative and toxic/very persistent and very bioaccumulative (PBTs/vPvBs) chemicals).

National regulations exist that require the containment of fire-water run-off, but the consultation suggested that containment is rarely 100% effective and there are concerns about the efficacy of removal of PFAS from collected fire-water in WWTP. Industry best practice measures aim to minimise the use and release of PFAS-based foams (e.g. ceasing its use in training and testing, as has happened in many locations already) but the consultation suggested that these are not being fully implemented (e.g. the use of PFAS-

²⁸ See Section B.9.3.2 for a discussion of how much of the total could be used for testing and training.

²⁹ See for instance Muir, D. et al. (2019): Levels and trends of poly- and perfluoroalkyl substances in the Arctic environment—An update. *Emerging Contaminants*, 5, 240–271.

³⁰ Cousins et al, 2018, 'short-chain perfluoroalkyl acids: environmental concerns and regulatory strategy under REACH', *Environmental science Europe* vol 30. Annex 3

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based foams in training has been reported). Stakeholder input did not allow to conclude on their relative effectiveness.

In conclusion, it has been demonstrated that the use of PFAS in fire-fighting foams is associated with a significant environmental concern that does not seem to be adequately addressed by the current measures in place (current measures are discussed in more detail in Section 1.3). Even if additional measures were introduced at Member State level (and the consultation has not raised anything suggesting that they will be), there is potential for discrepancies in the definitions and scope of any national restrictions (e.g. definition of substances covered, uses covered, concentration thresholds, transition periods). This has implications not only for the degree to which the environment is protected, but also in terms of ensuring the functioning of the internal market. Firefighting foams being traded over the borders, different restrictions in different Member States could make it very challenging to market fire-fighting foam products saleable in all Member States. It would therefore not be meaningful or possible to restrict them nationally due to internal market considerations. Moreover, due to their high mobility and persistence as well as their proven ubiquity (at least of some PFAS), it appears very likely that PFAS emissions lead to cross-border pollution. Therefore, potential further regulatory management on EU-level is likely required.

1.3. Baseline

1.3.1. Overview

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

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

The baseline scenario describes the situation in the absence of any further regulatory management options (RMOs). It reflects the current market situation, but also any anticipated changes in the absence of the proposed RMOs. It was used to compare restriction scenarios (defined in the next sub-section), to ensure that the SEA evaluates the impacts of the RMOs being assessed.

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

- It is estimated that currently some 14,000-20,000 tonnes (likely closer to the upper end of the range) of PFAS-based fire-fighting foams are sold per year in the EU and used in various sectors including chemicals/petrochemicals, municipal fire-fighting, marine, airports, military, railways and fire extinguishers. Their use is particularly important and widespread where there is a risk of Class B fires, i.e. where flammable liquids are present. They are used for fire-fighting, but in some cases also for training and testing of equipment.

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- Some 9,000 tonnes per year of fluorine-free foams are already used in most of the same applications, although the split by sector varies from that of PFAS-based foams. Several stakeholders, including manufacturers of fire-fighting foams, have indicated that the use of fluorine-free foams has been increasing, particularly in applications where PFAS-based foams can be very easily replaced (e.g. training). This trend is expected to continue in the future to some extent (even in the absence of any restriction on PFAS-based foams). Some stakeholders also noted that containment of fire-water run-off, particularly from training, has been increasing and that this has likely reduced emissions of PFAS significantly.
- In addition, there are significant existing stocks of PFAS containing foams which have been already purchased. These may need to be disposed of and replaced. The total quantum of these stocks is uncertain, but are estimated as follows:
 - Annual sales of PFAS-based foams are estimated at between 14,000-20,000 tonnes per year.
 - Current annual sales of fluorine-free foams are estimated at 7,000-9,000 tonnes per year. Historically, this demand would have been served by PFAS containing foams, hence the total annual sales of PFAS-based foams could have been some 21,000-29,000 tonnes.
 - The shelf life of PFAS-based foams is reported to be typically between 10 and 20 years (and up to a maximum of 30 years)³¹. Given that foams may be used before the end of their shelf life, the actual lifetime of foams could be shorter. BiPRO 2010 suggests that the average lifespan of fire-fighting foams is 15 years, which appears consistent with the above information³².
 - ~~A stock of PFAS foam of 62 500 tonnes in the EU is estimated. Given that between 14,000 and 29,000 tonnes of PFAS based foam have historically been replaced per year, and assuming an average lifespan of foams of 15 years, indicates that the existing European stocks of PFAS based foam may be between 210,000 and 435,000 tonnes~~³³. These volumes of stock are used in the SEA calculations.

1.3.3. Overview of current regulatory measures

1.3.3.1. Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants (POPs) includes restrictions on the production and use of a number of specific PFAS, at international level, including some

³¹ Proposal for a restriction: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances
<https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19>

³² BiPRO, 2010, Study on waste related issues of newly listed POPs and candidate POPs

³³ ~~Wood (2020) estimated a stock between 210 000 and 435 000 tonnes, however, comments from stakeholders on the PFHxA restriction proposal indicate that the figure of 62 500 tonnes would be more realistic (e.g. comment #3010 from FFCC available at in Part 2 document available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>). A lifespan of 15 years means that each year, 1/15 of the stocks are replaced. So, if between 14,000 to 29,000 tonnes are replaced per year, then the stock is 15 times that tonnage. Multiplying annual replacement tonnages with 15 yields the above estimates.~~

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provision for exemptions for the production and use of these compounds for use in firefighting foams.

PFOS, its salts and PFOSF are listed under Annex B of the Stockholm Convention, which restricts production and use to specified acceptable purposes and specific exemptions. Upon its initial listing in 2009, an acceptable purpose was put in place for PFOS used in firefighting foams. At the POPRC meeting in 2018, the committee recommended, based on the findings of an assessment of alternatives to PFOS³⁴, that the acceptable purposes for the production and use of PFOS, its salts and PFOSF for fire-fighting foam be amended to a specific exemption for the use of fire-fighting foam for liquid fuel vapour suppression and liquid fuel fires (Class B fires) already in installed systems, including both mobile and fixed systems, and with the same conditions put in place for PFOA (see below). This exemption was agreed accordingly at the Ninth Meeting of the Conference of the Parties (COP) to the Stockholm Convention in 2019.

At the 14th meeting of the POPRC in September 2018 the POPRC recommended listing PFOA, its salts and PFOA-related compounds in Annex A to the Convention with specific exemptions. One exemption specified was for use of firefighting foams containing PFOA already installed in systems including both mobile and fixed systems with specific conditions. Parties to the Convention can register for this exemption if they: i) ensure that FFFs that contain or may contain PFOA shall not be exported or imported except for the purpose of environmentally sound disposal; ii) do not use FFFs that contain or may contain PFOA for training or testing (unless all releases are contained) purposes; iii) by the end of 2022 if possible, but no later than 2025, restrict uses of FFFs that contain or may contain PFOA, to sites where all releases can be contained; iv) ensure all fire water, waste water, run-off, foam and other wastes are managed. This was also agreed accordingly at the 9th COP in 2019.

At its fifteenth meeting, the POPRC adopted the risk management evaluation on perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds and recommended to the Conference of the Parties that it consider listing the chemicals in Annex A to the Convention without specific exemptions. The listing will not be officially adopted until the next COP meeting in May 2021, and would be officially added to the Annexes of the Convention in 2022.

1.3.3.2. EU Regulation

The European Union has implemented the POPs Regulation (EC 2019/1021)³⁵ which acts to implement the provisions of the Stockholm Convention across the EU Member States.

PFOS was originally included in the restricted substances list of REACH. However, since its addition to the Stockholm Convention in 2009, it has been regulated under the POPs Regulation. PFOS, its salts and PFOSF are listed under Annex I of the POPs Regulation, specifying the following exemptions for unintentional trace contaminants (UTC)³⁶:

- Substances or preparations (<10 mg/kg)

³⁴ UNEP/POPS/POPRC.14/INF/8 : <http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC14/Overview/tabid/7398/Default.aspx>

³⁵ <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1021&from=EN>

³⁶ There is an exemption for the use in hard chromium plating, although that is not relevant for fire-fighting foams.

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- Semi-finished products or articles, or parts (<0.1 % by weight)

An exemption is also foreseen for the use as a mist suppressant for non-decorative hard chromium plating.

PFOA has been identified under REACH as a SVHC since 2013 and it is restricted under entry 68 of Annex XVII. However, the restriction includes an exemption for PFOA used in concentrated fire-fighting foam mixtures placed on the market before 4 July 2020 and those used in the production of other fire-fighting foam mixtures. There is also an exemption for use in fire-fighting foam mixtures produced before 4 July 2020 and used for training purposes, provided that emissions to the environment are minimised and effluents are collected and safely disposed of. [The POPs Regulation is expected to be amended in summer 2020 to include PFOA in Annex I following the listing under the Stockholm Convention (see above). The derogations for fire-fighting foams proposed under the POPs Regulation are more limited compared to the REACH restriction, as the listing under the Stockholm Convention allows no derogation for use in training; it only allows use of foams in installed systems, only until 2022 (or 2025 at the latest), and only with containment requirements.]

[PFHxS, has, since June 2017, also been listed as an SVHC under REACH and there is an ongoing restriction proposal³⁷ (at the time of writing at the stage of public consultation on the SEAC draft opinion). It is expected that PFHxS will ultimately also be regulated at EU-level under the POPs Regulation, when its listing to the Stockholm Convention is finalised (see above).

In December 2019, a proposal³⁸ for a restriction under REACH on PFHxA was published. The proposal includes certain transition periods and derogations for uses in fire-fighting foams. It is proposed that concentrated fire-fighting foam mixtures placed on the market until 18 months after the entry into force of the restriction could still be used in the production of other firefighting foam mixtures until 5 years after the entry into force, except for use of fire-fighting foam for training and (if not 100% contained) testing. There is also an exception for concentrated fire-fighting foam mixtures for certain defence applications until a successful transition to alternatives can be achieved, and for concentrated fire-fighting foam mixtures for cases of class B fires in storage tanks with a surface area above 500 m² until 12 years after the entry into force.]

1.3.3.3. Other international controls

In 2016, The Swedish Chemicals Agency (KEMI) published its strategy for reducing the use of PFASs³⁹ beyond solely the implementation of EU legislation. This included specific measures to tackle PFAS in firefighting foams, including a proposal for national regulations covering, for example:

- legal requirement for the collection and destruction of fluorine-based fire-fighting foam
- imposing reporting requirements

Commented [MD24]: To be updated with latest developments.

Commented [MD25]: To be updated based on latest developments.

³⁷ <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e1827f87da>

³⁸ <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d>

³⁹ <https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-highly-fluorinated-substances-pfas.pdf>

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- review of exemptions - with the aim of reducing the number of exemptions as much as possible

In some non-EU countries, there are also regulations in place, specifically targeting PFAS in firefighting foams. For example, in Norway⁴⁰, there are regulations in place that focus on the following:

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

In the USA, at federal level, the US EPA has developed and launched a PFAS Action Plan⁴¹ to evaluate whether and how to regulate PFAS compounds under various federal environmental programmes (including TSCA). The primary focus of this plan is to reduce environmental and public health concerns when PFAS are released into the environment (e.g., through setting safe drinking water limits and remediation criteria). While the plan specifically references the use of firefighting foams as a key source of PFAS contamination and exposure, it does not set limits or actions specifically at national level for use of PFAS in foams. In December 2019, the Fiscal Year 2020 National Defense Authorization Act (NDAA) was released, which phases out the US Department of Defense's use of PFAS-containing firefighting foam by October 2024 (with an exception for shipboard use) and immediately prohibits the uncontrolled release of fluorinated aqueous film-forming foam (AFFF) and the use of AFFF in training exercises at military installations⁴². It should be noted that individual States also implement their own measures, and there is a wide variety of approaches, measures, and timescales adopted. As an example of some of the States with the strictest approaches:

- Washington bans the sale and the use for training purposes of PFAS-based firefighting foams from 1 July 2020 (except for oil refineries, chemical plants and uses required by federal law such as aircraft rescue)⁴³.
- [In California, a bill was proposed to the Senate (but not yet passed at the time of writing) to ban, from the beginning of 2022, the placing on the market of firefighting foams with intentionally added PFAS, except for uses required by federal law. It also requires manufacturers to recall products affected by the ban by that date, practically banning the use as well⁴⁴].

Commented [MD26]: To be checked and updated.

In Australia, the biggest source of concentrated emissions of PFAS is from historical use of PFAS-containing fire-fighting foams, particularly at fire-fighting training grounds. The Industrial Chemicals (Notification and Assessment) Act (ICNA Act), requires industry to provide toxicity data for new substances (including PFASs) or products containing new

⁴⁰ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/norway.htm>

⁴¹ https://www.epa.gov/sites/production/files/2019-02/documents/pfas_action_plan_021319_508compliant_1.pdf

⁴² https://armedservices.house.gov/_cache/files/f/5/f50b2a93-79aa-42a0-a1aa-d1c490011bae/3552B8ED0CB74FB28CC88F434EFB306A.fy20-ndaa-conference-summary-final.pdf

⁴³ <http://lawfilesexternal.wa.gov/biennium/2017-18/Pdf/Bills/Senate%20Passed%20Legislature/6413-S.Pl.pdf?g=20200413062702>

⁴⁴ https://leginfo.ca.gov/faces/billCompareClient.xhtml?bill_id=201920200SB1044&showamends=false

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PFASs being introduced into Australia. Based on the level of toxicity and environmental persistence, the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) recommends restrictions on how these substances can and cannot be used⁴⁵.

1.3.4. Industry Measures

1.3.4.1. Substitution and phase-out

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

The use of C8-based AFFF has been largely phased out in favour of these alternatives. For example, it is reported that the volume of AFFF-containing PFOS used in the USA declined from around 21 million litres in 2004 to less than 9 million litres in 2011⁴⁶.

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

In the USA, in 2006, the US EPA launched the PFOA Stewardship Program following concerns raised about the impact of PFOA and long-chain PFASs on human health and the environment, including concerns about their persistence and presence in the environment⁴⁷. The programme involved eight major companies⁴⁸ committing to reducing PFOA from facility emissions and product content by 95 percent no later than 2010, and to work toward eliminating PFOA from emissions and product content no later than 2015. All participating companies state in the most recent progress reports, that they met the PFOA Stewardship Program goals⁴⁹.

In Australia, it has been reported that the Department of Defence commenced phasing out its use of PFOS and PFOA-containing fire-fighting foams and switched to 'Ansulite', which only contains trace elements of PFOS/PFOA and is only used in emergency situations or in controlled environments to test equipment. Furthermore, PFAS use is also limited by Air Services Australia, a government-owned corporation that provides air traffic control management, which has transitioned away from fluorinated firefighting foam to non-fluorinated firefighting foam including the destruction of remaining stockpiles⁵⁰.

⁴⁵ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/australia.htm>

⁴⁶ FFFC (2011) Estimated Inventory Of PFOS-based Aqueous Film Forming Foam (AFFF). 2011 update to the 2004 report entitled "Estimated Quantities of Aqueous Film Forming Foam (AFFF) In the United States". Prepared for the Fire Fighting Foam Coalition, Inc.

⁴⁷ <https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/fact-sheet-20102015-pfoa-stewardship-program>

⁴⁸ Arkema, Asahi, BASF, Clariant, Daikin, 3M/Dyneon, DuPont, Solvay Solexis

⁴⁹ <https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/20102015-pfoa-stewardship-program-2014-annual-progress>

⁵⁰ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/australia.htm>

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1.3.4.2. Containment and control

In Germany⁵¹, it is reported that the regulatory authorities and fire-fighting associations have compiled a leaflet on PFAS in fire-fighting, which has reportedly resulted in an increased awareness of the risks associated with certain PFASs by industry, NGOs and the public.

In Norway⁵² it is reported that fluorine-containing fire-fighting foam has been substituted with fluorine-free alternatives in most civil airports and fluorine-containing foam is no longer in use at fire-fighting training sites with the Norwegian military forces. Furthermore, it is reported that PFAS are being gradually substituted with fluorine free-alternatives in the offshore sector, and the volumes of fluorine-containing foam used in this sector are decreasing.

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

The trade association, the Fire Fighting Foam Coalition (FFFC) has published a best practice guidance document for the safe use of firefighting foams for Class B fires⁵³, with the aim to “foster use of foam in an environmentally responsible manner so as to minimize risk from its use”.

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

- **Foam Selection** – specifying situations where the use of Class B foams is, and is not, recommended, e.g. limiting the use of Class B foams to situations that present ‘a significant flammable liquid hazard’.
- **Eliminating Foam Discharge** – noting that this is not always possible in emergency situations, but emphasising the possibility to achieve this in training and the testing of foam systems and equipment.
- **Training** – providing guidance on the formulation of training foams, the design, construction and operation of training facilities.
- **Foam System Testing** – including guidance on acceptance tests, conducted pursuant to installation of the system; and maintenance tests (i.e. of firefighting vehicles).
- **Containing Foam Discharge** – guidance to prevent discharge to the environment, both for manual and fixed systems.
- **Firewater and foam concentrate disposal** – with an emphasis on incineration but also covering coagulation, flocculation, electro-flocculation, reverse osmosis, and adsorption on granular activated carbon (GAC).

⁵¹ <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/germany.htm>

⁵² <https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/norway.htm>

⁵³ Covering aqueous film-forming foam (AFFF), alcohol resistant aqueous film-forming foam (AR-AFFF), film-forming fluoroprotein foam (FFFP), alcohol resistant film-forming fluoroprotein foam (AR-FFFP), and fluoroprotein foam (FP, FPAR).

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Similarly, the Fire Protection Association Australia has published a guidance document on the selection and use of firefighting foams⁵⁴. This covers, for example,

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

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

2. Impact assessment

2.1. Introduction

This impact assessment is based primarily on a socio-economic analysis and regulatory management option analysis RMOA on a potential restriction (ban) on the placing on the market (and the use) of PFAS-based fire-fighting foams in the EU. A restriction on the manufacture (export) has also been assessed as well as the impact of the proposed regulatory options on the use and waste stages of fire-fighting foams.

2.2. Risk Management Options

~~Two~~^{Four} main regulatory management options (RMOs) have been assessed:

- 1) Restriction (ban) on the placing on the market of PFAS-based fire-fighting foams (hereafter referred to as RMO 1) with different transitional periods per type of use. The use of legacy foams, i.e. foams already in stock at producers' or users' sites, is still permitted.
- 2) Restriction (ban) on the placing on the market and the use of PFAS-based fire-fighting foams (hereafter referred to as RMO 2) with different transitional periods per type of use. The legacy foams, i.e. foams already in stock at producers' or users' sites, should be disposed of safely.
- ~~2)3)~~ Restriction on the manufacture, placing on the market and use of PFAS-based fire-fighting foams with different transitional periods per type of use.
- ~~3)4)~~ Restriction on the manufacture, placing on the market and use of PFAS-based fire-fighting foams with different transitional periods per type of use and the provision for a derogation mechanism via a permit system to which Seveso establishments would be eligible

Commented [MD27]: Scenario still to be developed.

Commented [MD28]: Scenario still to be developed, based on industry comments in the PFHxA opinion-making process.

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

⁵⁴ FPA Australia (2017)

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- Restriction of use in training, testing, municipal brigades and portable extinguishers only, other uses allowed until suitable alternatives are found + mandatory collection and treatment of concentrates and fire waters with techniques maximising mineralisation + reporting to ECHA and periodic review of the restriction for update of derogations

Issues: marine and offshore uses where collection and destruction is not possible, administrative burden for ECHA, much weaker incentive for substitution leading to continued emissions in the environment during an unknown but probably long period

- Restriction of use in training, testing, municipal brigades and portable extinguishers only + mandatory collection and treatment of concentrates and fire waters with techniques maximising mineralisation + inclusion of all PFAS in Annex XIV leading to AfAs for remaining uses

Issues: marine and offshore uses where collection and destruction is not possible; unlikely to have all PFAS included in the Candidate List and Authorisation List, AfA would encompass all types of PFAS uses, not only firefighting foams and AfA process unlikely to be able to judge on the need for PFAS foam with regard to fire safety such as major accidents dealt by the Seveso Directive requirements

2.3. Restriction scenarios

The (two figures below) summarise the main effects (i.e. anticipated responses from the supply chains along with associated impacts) resulting from the two restriction scenarios. These are identified based on literature review, the targeted stakeholder consultation, and discussions with the steering group. The large text in the solid green boxes summarises each effect in a brief headline, the smaller hollow boxes provide some additional commentary. The numbered boxes at the end of each chain represent the ultimate impacts to be assessed. These ultimate impacts are discussed one by one in Annex E, Section E.4.

Commented [MD29]: Will be complemented with RMO 3 and 4.

Figure 2.1 Map summarising potential effects of a restriction on the placing on the market of PFAS-based fire-fighting foams

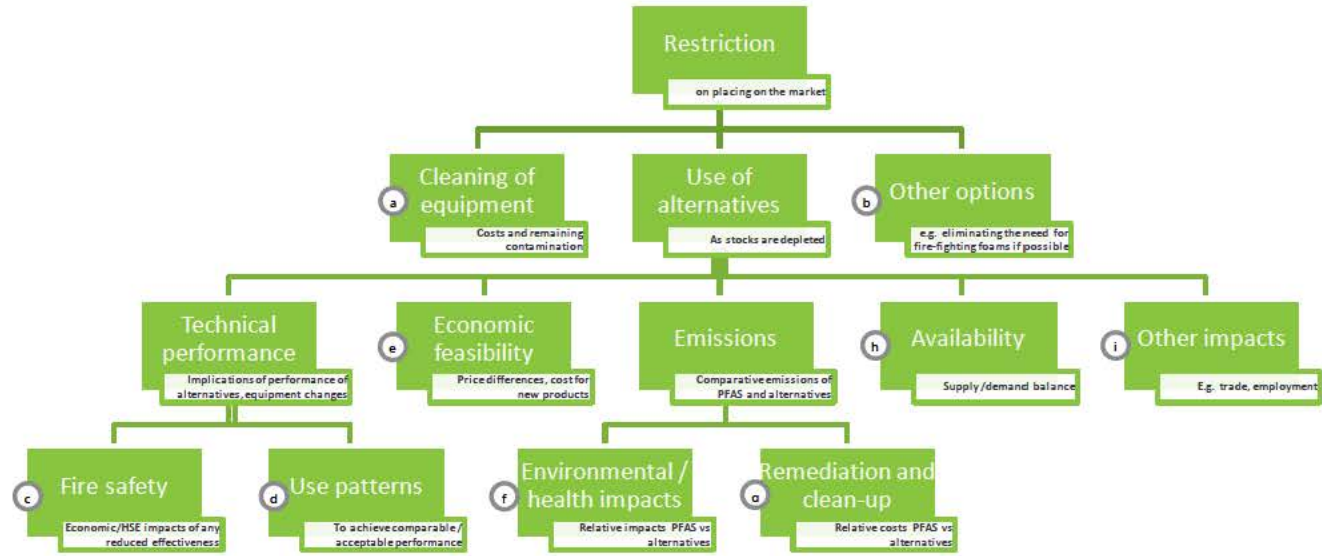
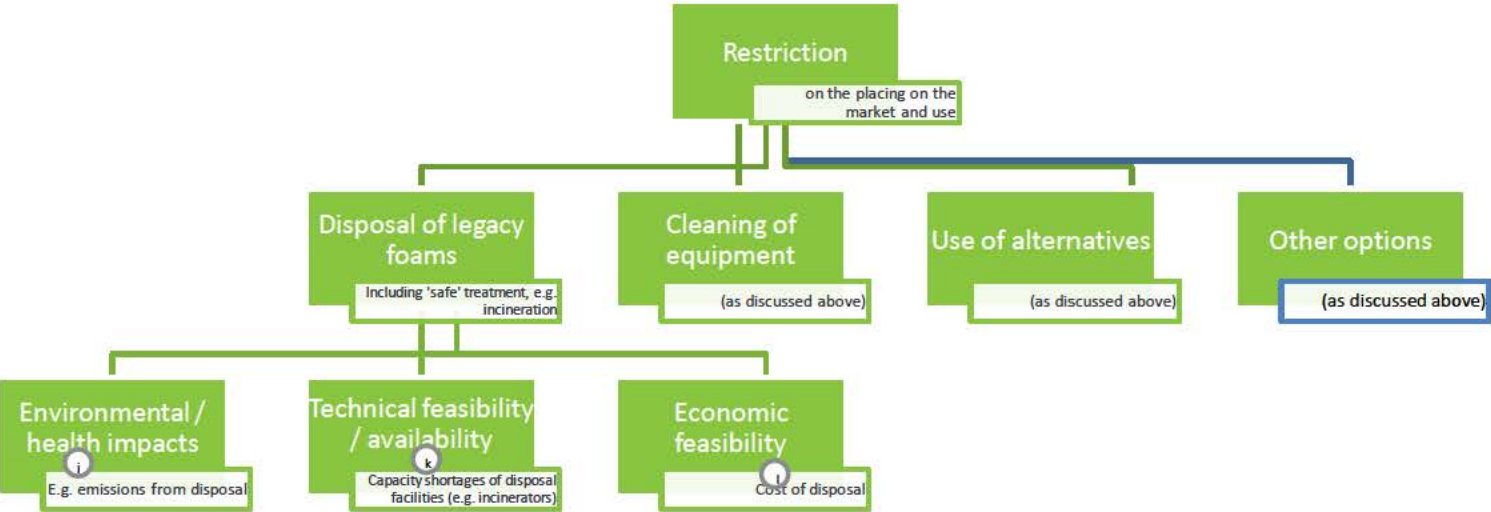


Figure 2.2 Map summarising potential effects of a restriction on the placing on the market and use of PFAS-based fire-fighting foams



Risk management option 4: Restriction on the manufacture, placing on the market and use with derogation mechanism via a permit system to which Seveso sites would be eligible

In response to questions from ECHA on transitional periods, Eurofeu relayed the joint position from the German associations for Mineral oil Industry (MWV) and the independent fuel storage operations (UTV) which developed a proposal in case ban on the use of PFAS foams would be implemented, to allow the sites covered under the Seveso directive⁵⁵ to apply to their local relevant authorities for a time-limited continued use of PFAS foams as part of their operation permit.

Eurofeu describes that the Seveso Directive requires an authorisation to deal with hazardous substances or fuels above certain volumes and sets out requirements for detailed risk assessment and risk mitigation measures including but not limited to fire protection.

Under this proposal, the establishments covered under the Seveso Directive could apply to their local relevant authorities for a time-limited derogation for the use of PFAS foams as part of their operation permit where the applicant would provide a justification for the need of using PFAS foams, a proof of the presence of firewater retention systems, a clear transition plan towards fluorine-free alternatives, regular reports on uses, replacements and disposal of PFAS foams and on substitution efforts and progress.

According to Eurofeu, the benefits of such a system are:

- the avoidance of derogations to the use ban that are non-flexible, difficult to manage and problematic to adhere to;
- that authorities have direct information on the use and consumption of PFAS foams, they control the conditions for granting exemptions from the restriction and have an already existing instrument to assess the site specificities through the measures foreseen in Seveso Directive requirements;
- only the companies which are in the need to use PFAS foams to manage severe fire risks would be granted a permit for using these foams, using a process for application, surveillance and reporting that is already in place.

Eurofeu provided a schematic description of the process (see embedded file below) and a translation in English of MWV/UTV's proposal which is originally in German:

"An alternative option is to establish an exemption for the continued use of fluorinated foam extinguishing agents based on certain conditions, which can be applied for by facilities and would be linked to their general operating permit:

Commented [MD30]: Below is described the proposal from industry. Assessment and discuss on of it still need to be performed.

⁵⁵ Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances

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Companies handling flammable liquids in a variety and/or quantity for which the continued use of AFFF foam extinguishing agents is recommended or even existential are typically subject to the so-called SEVESO III Directive ((EU) 2012/18) concerning the control of major accident hazards involving dangerous substances.

According to this directive, the handling of these substances requires an official permit, which already includes fire protection measures. The permit is issued on the basis of defined application forms, a defined procedure after examination and is reviewed on a recurring basis within the framework of the already existing monitoring systems by on-site inspections of the competent authorities in accordance with Article 20 of the SEVESO III Directive.

We propose to extend this operating license according to (EU) 2012/18 to the effect that companies can apply for an exemption for the temporary continued use of AFFF foam extinguishing agents and also receive it if it can be proven that the corresponding requirements are met.

These conditions could include, but are not limited to:

- A detailed justification for why fluorine-free extinguishing agents cannot be switched to immediately and AFFFs should continue to be used.

-Evidence of appropriate containment systems and disposal routes for all fluorinecontaminated extinguishing water.

- Regular detailed reports on the quantities of foam agents held, procured and used, as well as proof of disposal for unused AFFF foam agents that have been replaced.

- A detailed transition plan to fluorine-free extinguishing agents with verifiable targets. In establishing these targets, an effective combination of technical equipment and extinguishing agents must be the essential basis for the timing.

The requirements could be adapted to the respective state of the art/state of the general changeover, and a permit issued thereafter would be limited in time (e.g., to two to three years in line with the intervals of on-site inspections under the Major Accidents Ordinance).

This would - avoid attaching unrealistic and difficult-to-follow conditions to the exemptions (e.g. the exemption of tanks >500 square meters without taking their containment areas into account).

- Companies with particularly complex fire protection systems or for which an ad hoc conversion would be particularly difficult economically, were given the opportunity to adapt the conversion to their performance capacity.

- In return, the authorities are given the opportunity to obtain very precise information on the material flows via the application data, to flexibly adapt the approval requirements to the general state of development, and thus to be able to phase out fluorine technology at maximum speed with minimum risk.

- In addition, the existing monitoring system under Article 20 of the SEVESO III Directive provides the authorities with an overview of the foam extinguishing agents held, used and procured during the recurring on-site inspections at the plants."



Visio-AFFF%20perm
itting%20process.pc

Field Code Changed

2.4. Economic impacts

Commented [MD31]: To be updated with new data from stakeholders' survey and addition of RMO 3 and 4.

Risk management options (RMO) 1 and 2 require purchasing of alternative foams which is estimated to incur additional costs (compared to the baseline) of around €27m per year in the EU. In RMO 2, these costs would be incurred immediately when the restriction comes into force (or before), whereas in RMO 1 the costs increase gradually and only reach €27m per year once all stocks are depleted. This would be partly off-set by savings, e.g. from lower disposal cost of fluorine-free foams when they reach their expiry date.

However, RMO 2 would also require existing stocks of PFAS-based foams (estimated ~~210 000 435 000 62 500~~ tonnes) to be written off (considering depreciation since their purchase), and new stocks would have to be purchased, subject to replacement costs (minus the value of existing stocks already depreciated) estimated at around €1.0 billion (range -€60 million⁵⁶ to €8.3 billion).

In RMO 2, additional costs would also be incurred for the disposal of the existing stocks of PFAS-based foams. Total EU costs (one-off) are estimated at up to €320 million (range up to €60m-€4.8bn) depending on the method used and the share of foams that would have reached expiry date without use (whose disposal is merely brought forward by the restriction, but costs are not additional to the baseline). There is a trade-off between the disposal costs and the mitigation of potential environmental risks from disposal (as discussed above). Additional transport, storage and labour costs have not been quantified.

There are other potential economic costs for transitioning that are difficult to quantify, of which cleaning/replacement of equipment before switching the foam are likely the most important. These costs could be significant (e.g. cleaning could potentially be in the order of €1 billion, depending on the residual concentration limit and number of installations affected). They are not likely to vary significantly across the two options but could be more spread over time under RMO 1.

Alternatives are generally considered to be technically feasible in most applications (see Annex E.2). Further testing is required to confirm the technical feasibility of alternatives for specific applications, particularly in the oil and chemical sector with installations with large atmospheric storage tanks or different types of flammable liquids. The speed of fire suppression may be slower and application of foams may be less flexible and less easy to use (e.g. different foams may be needed for different flammable liquids), in some cases. This may have further economic impacts that have not been

⁵⁶ I.e. a potential saving of €60 million, if fluorine-free alternatives are less expensive than the PFAS-based foams they replace (possible in some cases but unlikely on average) and no additional volumes are required.

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quantified. In RMO 1 some of these risks would be mitigated for as long as stocks of PFAS-based foams in existing systems are being used.

There are **potentially significant benefits in terms of reduced clean-up and remediation costs**. As a very high level estimate for illustration, the potential order of magnitude of avoided remediation could be hundreds of millions or Euros (assuming tens of sites requiring remediation at tens of millions of Euro per site) to billions of Euros (assuming hundreds of sites requiring remediation at tens of millions of Euro per site). More information on the total number of sites, real-world use of PFAS per site as well as implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess to which extent remediation is likely to be required in the future as a result of current use of PFAS-based fire-fighting foams (and could therefore be avoided because of the restriction). Any such benefits would be higher in RMO 2, given the quicker elimination of PFAS emissions and higher reductions of accumulated PFAS contamination.

Treatment of fire-water run-off and short-term clean-up after the use of fire-fighting foams is largely driven by other components of the fire-water run-off, rather than the foam used. At least in some cases, run-off treatment costs could be around €0.7 per litre (range ca €0-€11) or up to tens of millions of Euro per incident cheaper when fluorine-free foams are used, but data on the total amount of fire-water run-off treated was lacking to quantify an EU total (see Annex E.4.1.g. for a more detailed discussion). In cases where fire-water run-off is not contained and further clean-up is possible, clean-up costs may also be lower for fluorine-free foams due to their lower persistence. No specific data was available to quantify this saving, but for illustration the potential order of magnitude of savings could be several million Euros (assuming several tens of incidents per year using PFAS-based foams where clean-up is required and which could be avoided if fluorine-free foams were used). Again, any such benefits would be higher in RMO 2, given the quicker elimination of PFAS emissions and higher reductions of accumulated PFAS contamination.

It is considered unlikely that either scenario will cause any significant macroeconomic impacts (e.g. employment, trade).

2.5. Human health and environmental impacts

RMO 1 and 2 will eventually lead to an elimination of the use and therefore the emissions of PFAS-containing fire-fighting foams. Therefore, they can both be considered effective in addressing the identified concern and eliminating any further human health and environmental impacts of PFAS exposure related to the use of fire-fighting foams (noting that impacts of exposure related to legacy emissions may continue for a long time, considering the persistence of PFAS). The reduction of emissions would be achieved more quickly in RMO 2 and therefore RMO 2 would also achieve a higher reduction of accumulative PFAS contamination. Estimations of the evolution of the emissions of PFAS in the environment under the main RMOs and with different transitional periods per type of use are presented below.

XXXX

Commented [MD32]: Under elaboration.

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The shelf life of PFAS-based foams is reported to be typically between 10 and 20 years (to a maximum of 30 years)⁵⁷, so in RMO 1 some (decreasing) emissions of PFAS-based foam could continue for a long period after the entry into force of the restriction. In Wood (2020), based on the annual sales and average lifetime of fire-fighting foams, it was estimated that the stocks of PFAS-based fire-fighting foams in existing systems may be between 210,000 and 435,000 tonnes (see Annex A). However, based on the comment from FFFC⁵⁸ in the PFHxA restriction proposal these figures are unlikely and the figure of 62 500 tonnes is argued to be more realistic. ~~It nevertheless remain~~ is uncertain what share of foams in existing systems would be used (and hence to some extent emitted) and what share would be replaced at the end of their shelf life or replaced voluntarily (and hence disposed of safely).

It should be noted that in RMO 2, there are potential risks of emissions from the incineration of legacy foams, but further research is needed to identify and quantify the emissions produced from the incineration of PFAS.

As mentioned above, the analysis of alternatives (see Annex E.2) has concluded that alternatives are generally considered to be technically feasible in most applications. Further testing is required to confirm the technical feasibility of alternatives for specific applications, particularly large atmospheric storage tanks. The speed of fire suppression may be slower, the required foam application rate might be higher, and application of foams may be less flexible and less easy to use (e.g. different foams may be needed for different flammable liquids), in some cases. Some stakeholders have indicated that PFAS firefighting foams are more "forgiving" than fluorine-free alternatives in terms of application conditions, i.e. PFAS foams remain effective despite some variations with the ideal application parameters (e.g. water/PFAS surfactant proportion, application rate and strength, water quality), which would be less true for fluorine-free foams, considered more sensitive to differences to the ideal use parameters⁵⁹. If not properly managed, these risks could have human health impacts that have not been quantified. In RMO 1 some of these risks would be mitigated for as long as stocks of PFAS in existing systems are being used for the cases in question.

Commented [MD33]: Ongoing investigations by Ramboll on disposal methods and their emissions of contaminants.

2.6. Other impacts, practicability and monitorability

RMO 1 and 2 appear practical and monitorable, as there are already other regulations in place controlling the placing on the market and use of fire-fighting foams. However, as RMO 2 covers the use in addition to the placing on the market (which is also covered under RMO 1), it is subject to more complex requirements in terms of implementation, enforcement, management and monitoring, compared to RMO 1.

⁵⁷ Proposal for a restriction on: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances <https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19>

⁵⁸ Comment 3010 in Part 2 document available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

⁵⁹ E.g. MWV-UTV Positionspapier: "Evaluation of the fire protection effectiveness of fluorine free firefighting foams". Fire Protection Research Foundation report, January 2020: <https://www.nfpa.org/News-and-Research/Data-research-and-tools/Suppression/Evaluation-of-the-fire-protection-effectiveness-of-fluorine-free-firefighting-foams>; Eurofeu, 2019 - Position Paper on Fluorine containing firefighting Foams - Responsible Use of AFFF and the likes

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One stakeholder pointed out the following practicality issue for RMO 1. When large amounts of foam are used for an incident, foam tanks need to be quickly refilled to allow continued operation, sometimes even during the same incident. However, it is not recommended to mix different foams in the same system (because this could affect performance and the new foam would be contaminated with PFAS from the old foam), so refilling during an incident would not be feasible if PFAS-foam was used in existing systems. This could potentially lead to end-users building up stocks of PFAS-based foams before the restrictions comes into place, or it could potentially lead to users not replacing foams in existing systems to save costs, possibly causing problems during a large incident when a refill during the incident would be needed.

2.7. Proportionality (including comparison of options)

The key consideration in judging and comparing the appropriateness of the two RMOs is the balance between their effectiveness (i.e. the reduction of PFAS emissions) and their socio-economic impacts (primarily the costs of transitioning to fluorine-free foams and potentially fire-safety risks from using alternatives, off-set partly by benefits of reduced clean-up / remediation). As the environmental/health benefits of reduced PFAS emissions (and some of the socio-economic impacts) could not be quantified, it is not possible to use cost-benefit analysis to directly assess if the proposed intervention is proportionate. ECHA's approach to the "Evaluation of restriction reports and applications for authorisation for PBT and vPvB substances in SEAC"⁶⁰ uses the cost per unit (e.g. kilogram) of emission reduced. Based on the quantifiable socio-economic impacts, as a central estimate, it was calculated that **the cost effectiveness could be around €850 (RMO 1) to €1,700 (RMO 2) per kg of annual reduction of PFAS emissions. However, this could range from savings in the €10s per kg to costs around €10,000 per kg**⁶¹. The full calculations are presented in Annex E, Section E.5.

Commented [MD34]: To be updated and refined based on new data to be received from stakeholders and new assumptions to reduce the range of costs.

Therefore, the approach adopted in the following is to identify the uses/applications and conditions (transition periods, concentration thresholds, other risk management measures) that would achieve relatively high levels of effectiveness (i.e. reductions of PFAS emissions) with relatively small adverse socio-economic impacts. The fire-safety risk from using alternatives is considered by setting different transitional periods for different sectors to allow development of alternatives.

2.7.1. Comparison of different users

The various user sectors and applications of fire-fighting foams vary significantly in terms of the potential for a restriction to reduce PFAS emissions to the environment ('PFAS risk reduction potential'), the feasibility of transitioning to fluorine-free alternatives ('substitution potential') and the resulting potential socio-economic impacts of that transition. Therefore, it may be appropriate for regulatory management to set different conditions for the different

⁶⁰ https://echa.europa.eu/documents/10162/13580/evaluation_pbt_vpvb_substances_seac_en.pdf/af4a7207-f7ad-4ef3-ac68-685f70ab2db3

⁶¹ The wide variance of the range is primarily due to the significant uncertainty associated with the quantification of some costs and benefits. For instance, a saving could be achieved if the benefits in terms of reduced costs for remediation, clean-up and fire-water-run-off treatment are at the higher end of their estimated ranges and the costs in terms of disposal of stocks, cleaning of equipment, replacement of foam stocks are at the lower end of their estimated ranges, and vice-versa for the highest possible emission reduction costs per kg.

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sectors and applications, in order to balance the effectiveness of the measure with considerations around feasibility of alternatives and socio-economic impacts.

A table summarising and comparing substitution potential, socio-economic impacts and risk profile across the main identified user sectors is provided in Annex E.8.1.

The comparison in the table suggests that training and testing should be the highest priority for a quick transition to fluorine-free foams, because the use of alternatives is well established and already recommended as industry best practice. Training accounts for the majority of fire-fighting foam use (although likely not for the majority of PFAS emissions) and the potential for adverse socio-economic impacts is very low for training and testing.

Commented [MD35]: Under further investigation. Stakeholders claim that nowadays the majority of the training is done with F-free foams.

Chemical / petrochemical are the largest user sector meaning that the costs of transitioning but also the current risk of PFAS emissions are higher. However, derogations with a longer transition period may be needed for specific applications (notably large tank fires and installations using different types of flammable liquids) where further testing is required to determine the technical feasibility of alternatives and potential fire-safety risks from using alternatives are high. In these specific cases the socio-economic implications could outweigh the potential benefits in terms of PFAS emissions until more suitable alternatives have been developed and tested. (Note that further testing on the feasibility of alternatives was planned by LASTFIRE⁶² in 2020 but postponed due to the COVID-19 pandemic.)

Commented [MD36]: To be updated with latest info.

A rapid transition in marine applications should be a high priority due to its low potential for retention of run-off and clean-up after incidents, and established alternatives (e.g. two of the alternatives shortlisted in the analysis of alternatives were reported to be used in the marine sector).

Commented [MD37]: Under investigation with stakeholders if this would be possible.

Municipal fire services and ready-to-use applications (e.g. portable extinguishers) should also be priorities for a quick transition because alternatives are well-established and these sectors may involve fire incidents outside of specific industrial sites where there is a risk that retention of run-off and clean-up after incidents are more difficult.

Alternatives are less well established in the military sector, but they are considered by stakeholders to be feasible, have been adopted by the Danish and Norwegian armed forces⁶³, and the applications are similar to those of other similar sectors (with similar activities such as aerospace), where substitution has taken place. (Transition is probably possible but requires extra care because if the use of alternative caused any fire-safety risks, the potential damages could be significant and could include danger to human life.)

Commented [MD38]: Under further investigation.

Also in civil aviation there is the concern that if the use of alternative caused any fire-safety risks, the potential damages could be significant and would likely include danger to human life. However, alternatives are considered feasible and have successfully been implemented by many users (e.g. the airports of Dubai, Dortmund, Stuttgart, London Heathrow, Manchester, Copenhagen, Australia and Auckland), so this is considered unlikely and a relatively quick transition should be sought, as has been achieved elsewhere.

Commented [MD39]: Eurofeu claims that the defence sector is not much different than e.g. the aviation sector where a relatively quick transition is foreseeable.

⁶² A project by the oil and petrochemical industries to assess fire hazards of Large Atmospheric Storage Tanks (see www.lastfire.co.uk).

⁶³ According to the IPEN publication on "Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams (AFFF)".

2.7.2. Transition periods

Based on input from a range of stakeholders (see Annex E.8.2), different transition periods have been considered appropriate for different uses.

Successful transition to fluorine-free foams for training and testing has been reported by stakeholders across sectors and is already recommended as industry best practice. Therefore, only a short transition period may not be required for training and testing. In terms of the use for real fire incidents, oil and gas / petrochemicals are the only sector where users have suggested a longer transition period of up to 10 to 12 years is required, to conduct further testing of the feasibility of alternatives for large atmospheric storage tanks⁶⁴ (LAST), among other things. This is broadly consistent with the reported duration of the transition by Norwegian oil and gas company Equinor (see case study 2 in Annex E, Section E.2.), which took about 8 years from development and testing to full operation of fluorine-free alternatives. Oil and gas / petrochemicals is the largest user sector, so in order to ensure effectiveness of the regulation in reducing PFAS-emissions, the transition period should be limited to the most sensitive applications within this sector, particularly large incidents and LAST which could be defined as the installations subject to the Seveso Directive on major accident hazards.

For small incidents as well as all other sectors (e.g. Marine Applications, Military, Civil Aviation, Municipal Fire Services, Ready to use applications), shorter transition periods between 3-6 years have been suggested and are expected to minimise socio-economic implications of the restriction. However, considering the difficulty of establishing a definition of "small incidents" which would allow law enforcement, this categorisation of use is not taken forward in the restriction proposal.

Based on a study published January 2020 by the US Fire Protection Research Foundation⁶⁵ even though fluorine-free foams seem to overall perform well against different types of fuels, different application rates and methods may be needed to achieve the desired effect, resulting in the need to implement several technical adaptations to the overall fire extinguishing system of a site, including foam storage tanks and bunds (see details in section E.2.5). Sufficient time is therefore needed to allow users to implement these technical adaptations to transition to PFAS-free alternatives in order to maintain the necessary fire safety levels. These concerns have been also expressed by several industry stakeholders during the consultations undertaken during the preparation of this restriction proposal and the consultation on the PFHxA restriction proposal.

Based on the above, it is proposed to set transitional periods adapted to each type of use to allow the testing and selection of the most appropriate foam product and the adaptation or replacement of the fire extinguishing system, or replacement of parts thereof, including foam tanks and bunds:

⁶⁴ These are large diameter (greater than 40m) open top floating roof storage tanks of flammable liquids.

⁶⁵ "Evaluation of the fire protection effectiveness of fluorine free firefighting foams". Fire Protection Research Foundation report, January 2020: <https://www.nfpa.org/News-and-Research/Data-research-and-tools/Suppression/Evaluation-of-the-fire-protection-effectiveness-of-fluorine-free-firefighting-foams>

Commented [MD40]: We are working on concrete proposals of transition periods per types of use and trying to define more precisely these types of uses.

Cfr. proposed restriction entry at the beginning of this document

2.7.3. Concentration thresholds

There are two main considerations to choose appropriate thresholds for remaining PFAS-contamination in fire-fighting foams: the costs of cleaning and replacement of equipment which are strongly dependent on the concentration threshold chosen, and detection limits.

Costs of cleaning and achievable/detectable concentrations are discussed in more detail in Annex E (Section E.4, sub-section a. Cleaning of equipment), but key messages are summarised below.

There was a **wide divergence in opinion on appropriate concentration thresholds ranging from 10 ppb to 50,000 ppb** (stakeholder input is provided in Annex E.8.3). The available information suggests that 100 ppb can be achieved with a relatively simple cleaning process (cost likely low but not quantified) while 1 ppb is achievable with more complex and costly processes.

There is a trade-off between the amount of PFAS emissions remaining if a given threshold is adopted and the costs of cleaning imposed in order to achieve that threshold. For example, if the concentration of PFAS in the foam concentrate is in average 2.5%, i.e. 25 000 ppm or 25 000 000 ppb, a threshold of 100 ppb would lead to a reduction of concentration (and hence emissions) of 99.99%, while a threshold of 50 000 ppb would represent a reduction in concentration and emissions of 99.80%. A threshold of 10 000 ppb is 2 500 times lower than the average concentration of PFAS in the firefighting foams in use (understood to be the concentration needed to reach functionality) and therefore would impede any intentional use of PFAS in the foam concentrate.

From the stakeholder's consultation and literature review, the following conclusions can be made for available cleaning procedures for firefighting equipment:

- Procedures are authored by regional (Germany) and national (Australia) authorities, private companies (PerfluorAd & Arcadis), associations and lastly by manufacturers of foams (BioEx);
- All of them use extensive cleaning steps with (sometimes hot) water, which can also soak in overnight;
- The commercial technique uses also cleaning agents which precipitate the PFAS;
- In some, a replacement of highly contaminated material is suggested to avoid high remaining PFAS-concentrations;
- The success (remaining PFAS concentration) is measured using a variety of analytical techniques and respective PFAS-species.
- Most of the procedures are for fire brigade vehicles and/or tanks;
- Two procedures are also claiming to be suitable to installed firefighting systems (sprinkles);
- In most cases, incineration of the cleaning water is recommended;

Commented [MD41]: Ramboll is investigating the level of achievable thresholds and related costs.

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- Only very limited data for long-term success of cleaning procedures.

For fire brigade vehicles and for stationary fire extinguishing system Arcadis' method indicates reaching final water rinse containing around 0.1 µg/l (0.1 ppb) PFAS as measured for the sum of 28 PFAS (according to TOP 4 µg/l) but no cost information was available.

The PerfluorAd technique would lead to less than 1.0 µg/l (1ppb) total PFAS, even often less than 0.3 µg/l (0.3 ppb) with €20 000 to €25 000 per vehicle.

The LfU method could reach levels as low as 10 ng/l (10 ppt) of each of the 13 standard PFAS (according to German DIN standard) with costs of €100 000 to €200 000 per vehicle.

For vehicles and tanks, the methods proposed by FRV and FPA Australia could lead to levels of 70 ppt as measured by sum of PFOA and sum of PFHxS and PFOS, however, no cost information was provided.

WFVD indicates fire brigade vehicles cleaning reaching levels around the µg/l of each of the 13 standard PFAS (according to German DIN standard) with costs of € 4 000 per vehicle.

2.7.4. Firefighting foams disposal methods

The incineration of PFAS-containing firefighting foams is the most used disposal method. Literature indicates that waste incinerators at temperatures of 900 °C are able to destroy PFOS at more than 99%. A destruction efficiency of more than 99.97 % for fluorotelomers, chlorofluorocarbons and PTFE in conventional waste incineration was also reported. However, this process might not lead to the complete mineralisation of the PFAS i.e. the decomposition of the PFAS to CO₂, water, and hydrogen fluoride. At these temperatures short chain fluorinated compounds such as CF₄, C₂F₆, CHF₃, C₂H₂F₂ and C₃F₈ can be formed and released to the air. Literature indicates that temperatures of at least 1,400 °C are needed to destroy CF₄ and as such completely mineralise the PFAS. Literature indicates, that 1,100 °C is sufficiently hot and feasible for the destruction of PFAS, however no study has provided quantitative results on possible fluorinated gas emissions.

The average cost of approximately 1€/l is comparatively cheap but the process requires high amounts of energy as the water needs to be vapourised.

The co-incineration of PFAS waste in cement kilns is a viable alternative to incineration in HWI, as these kilns reach temperatures of up to 1,800 °C with residence times of ~20 seconds. It has been shown that the addition of calcium fluoride can increase the quality of the clinker. Additionally, calcium salts can decrease the decomposition temperature of PFAS and increase the mineralisation rate by forming calcium fluoride. Through the addition of PFAS-containing waste to the clinker production in-situ calcium fluoride can be formed, which can increase the clinker quality and destroy the PFAS. The applicability of liquid AFFF concentrate in the cement kilns is yet unknown.

More detailed information on disposal methods for firefighting foam concentrates is available in section XXX of the Annex.

However, stakeholders from Germany indicated, that cement kilns don't have the same filter techniques as HWIs (DUS-Valentin-Interview 2021). In addition, the cement could also be contaminated (LASTFIRE-Interview 2021).

2.7.5. Disposal of PFAS-contaminated (fire run off and cleaning) water

The following conclusions can be made for available disposal options for PFAS-contaminated (fire run off and cleaning) water:

- Fire run off and cleaning water are highly PFAS-contaminated compared to for example groundwater techniques. Based on this not all available remediation techniques for groundwater can be used also for run off and cleaning water.
- Granulated activated carbon (GAC) can be also used for all PFAS-contaminated for run off and cleaning water. However, the efficiency is lower for PFAAs (carboxylic acid) in general and short chain PFAS. For other PFAS (e.g. zwitterionic) no data is available. One stakeholder brought up that when GAC is reactivated (using 800 °C) PFAS could be emitted.
- Ion exchange (IX) is generally suited for PFAS-contaminated run off and cleaning water. However, no caste studies are available. Based on the type of PFAS various IX-matrices are available. IX is believed to be 4 times more expensive than GAC.
- GAC and IX are generally based on column beds to which PFAS absorb. To achieve certain PFAS-levels several beds in series must be used.
- To minimize the load (and therefore costs) of GAC/IX, precipitating agents like PerfluorAd can be used. The active ingredient changes the solubility of PFAS. PFAS-PerfluorAd sludge can be incinerated. The water then is then further treated with GAC/IX (treatment train).
- Ozonofraction uses the fact that PFAS remain the air-water interface and creates ozone-bubbles which are considerably smaller than regular air-bubbles. Bubbles then can be physically removed. The water then is then further treated with GAC/IX (treatment train).
- PFAS-contaminated fire run off and cleaning water can also be directly subjected to incineration.

More detailed information on the available techniques and associated costs of firewater treatments is available in section E.4.1 of the Annex.

2.7.4-2.7.6. Other risk management targeted at reducing release

Industry best practice guidance (e.g. from the Fire Fighting Foam Coalition⁶⁶) and regulations or guidelines in some EU Member States (e.g. England and Wales⁶⁷, Bavaria⁶⁸) already recommend or impose a range of measures to reduce the risk to the environment from the use of fire-fighting foams (see Section 1.3). These cover for instance containment, treatment,

⁶⁶ <https://www.fffc.org/>

⁶⁷ Environmental Protection Handbook for the Fire and Rescue Service, <https://www.ukfrs.com/sites/default/files/2017-09/Environment%20Agency%20and%20DCLG%20environmental%20handbook.pdf>

⁶⁸ <https://www.oecd.org/chem/calsafety/portal-perfluorinated-chemicals/countryinformation/germany.htm>

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and proper disposal of foams and fire water run-off. However, it is not clear to what extent these practices are being implemented or what their relative effectiveness is.

Stakeholder input to the consultation has also highlighted the importance of such measures to reduce emissions of PFAS-based foams, with recommendations made to legally impose retention systems, proof of proper disposal of any contaminated water/liquid, and use of appropriate PPE and cleaning procedures for after-use treatment.

A stakeholder also suggested supporting the transition with mandatory fire management plans for every site, which would include a description of the procedure and reasons for the procurement of the specific fire-fighting foams, their storage, use, recovery, containment and treatment. They also proposed setting up centrally managed stocks at specific, well-contained sites in large industrial areas that could be made available to potential users in case of emergencies, in order to control and restrict the use of PFAS-based foams to only the necessary applications during the transition period. This suggestion could help reduce the risk to the environment while allowing a potentially longer period to transition to alternatives, particularly for large industrial sites.

In conclusion, a restriction on the use of PFAS in firefighting foams should consider the obligation to apply best practice emission reduction measures during and after the use of PFAS-based fire-fighting foam during the transition periods when PFAS-based foams continue to be used under RMO 1.

Therefore, it is proposed that the restriction should require industrial and professional users of firefighting foam concentrates containing PFAS above the defined threshold:

- a. only use these foams for fires involving flammable liquids ("class B fires");
- b. establish a fire management plan for every site and type of foam use which would include a description of the procedure and reasons for the procurement of the specific fire-fighting foam concentrates, their storage, use, containment and treatment and the efforts made to search for PFAS-free alternatives. The fire management plan shall: (i) aim at reducing the use of PFAS foams to the minimum necessary while transitioning to PFAS-free foams, (ii) be reviewed annually and kept available for enforcement authorities;
- c. ensure the minimisation of emissions of PFAS in the environment and direct and indirect exposure to humans from all activities related to firefighting such as but not limited to: the use of foam concentrates, water-added foams, fire waters, mixtures used to clean the equipment containing PFAS firefighting foams by applying sector best practices.

The measures shall ensure:

- (iv) an adequate protection of workers using PFAS firefighting foams
- (v) the maximisation of the collection of the waste
- (vi) that the waste disposal uses methods maximising the mineralisation of the PFAS substances to the extent feasible. For each event of foam use or leakage handling, proof of appropriate management and disposal of the foam concentrates, water-added foams and fire water should be documented and kept available for enforcement authorities.

In addition, from six months after entry into force onwards, firefighting foam concentrates containing PFAS above the indicated threshold which are held in stocks and need to be disposed of shall be treated with techniques maximising the mineralisation of the PFAS

substances. Proof of appropriate disposal should be documented and kept available for enforcement authorities.

3. Assumptions, uncertainties and sensitivities

See Annex F.

4. Conclusion

Section 1.1.1.7 discussed the need for further regulatory management of the concerns associated with the use of PFAS in fire-fighting foams, based on the following:

- Significant hazards have been shown at least for some PFAS, including some short-chain PFAS.
- Many PFAS are highly mobile, highly persistent, and have the potential to accumulate within the environment and living organisms.
- The continued use of PFAS-based fire-fighting foams and resulting releases to the environment.
- A lack of existing regulation, and of implementation or proven effectiveness of other risk management measures to address the release of PFAS from the use of PFAS-based fire-fighting foams.

A restriction under REACH on the placing on the market only or on the placing on the market and use of PFAS-containing firefighting foams appears to be an appropriate option because:

- Alternatives are considered feasible for most applications (all except large atmospheric storage tanks), so that PFAS emissions can be eliminated by using fluorine-free products. However, a transitional period would be needed, adapted to each type of use to allow the testing and selection of the most appropriate foam product and the adaptation of the fire extinguishing system, or replacement of parts thereof, including foam tanks and bunds;
- Other risk management measures that could reduce release of PFAS to the environment are available and are to some extent already being applied; however, these appear unlikely to eliminate the emissions of PFAS from the use of fire-fighting foams as effectively.

It appears advisable to address the concern at EU-level, because there is no indication that Member State measures will be forthcoming, and any potential discrepancies in national-level management could have implications for the degree to which the environment is protected and for the functioning of the internal market for fire-fighting foam products. Firefighting foams are traded over the borders and it would not be meaningful or possible to restrict them nationally due to internal market considerations.

Furthermore, due to their high mobility and persistence as well as their ubiquity (at least of some PFAS), it appears very likely that PFAS emissions could lead to cross-border pollution.

Section 2 assessed the potential conditions of a restriction, in terms of whether it would ban only the placing on the market of PFAS-based fire-fighting foams, or both the placing on the market and the use of those foams. Potential variations across different user sectors, transition periods, concentration thresholds, and potential combination with other risk management measures are also relevant. Two main options have been considered:

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- A **ban on the placing on the market** would allow continued use of existing stocks of PFAS-based fire-fighting foams, which have been estimated at **between 210,000 and 435,000** tonnes. PFAS emissions related to their use could continue, and this may last for some 10-30 years after the entry into force of the restriction, based on the shelf-life of fire-fighting foams. When stocks are depleted, users would need to buy alternative foams incurring additional costs (compared to the baseline) of around €27m per year in the EU due to potentially higher volumes of alternative foams needed to achieve the desired performance. Before that, installations would need to be cleaned or replaced at potentially significant one-off cost (cleaning could potentially be in the order of up to €1 billion). This would be at least partly off-set by savings, e.g. from lower disposal cost of fire-water run-off (total difficult to quantify) and fluorine-free foams when they reach their expiry date (potentially €100,000s to € millions per year), and from reduced clean-up (potentially up to €10s of millions) / remediation costs (potentially up to € billions over a long time span). However, more information on the total number of sites, real-world use of PFAS per site as well as implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess the extent to which remediation and clean-up could be avoided by using fluorine-free fire-fighting foams. More details on uncertainties, ranges and other potential impacts are presented in Annex F.
- A **ban on the placing on the market and the use** of PFAS-based fire-fighting foams would immediately stop the emissions from the use of PFAS-based fire-fighting foams. This increased effectiveness needs to be weighed against the additional socio-economic implications. The existing stocks of PFAS-based fire-fighting foams would need to be disposed of (incineration costs estimated at €320 million) and new stocks would need be purchased (subject to replacement costs minus the value of existing stocks already depreciated estimated at around €1 billion). Furthermore, roll-out by suppliers and training/familiarisation would need to be done in a much more compressed timescale, but any potential savings from using alternatives (as discussed above) would also be incurred more quickly.
- **ban on the manufacture, the placing on the market and the use**
- **other RMOs (tbd)**

Commented [MD42]: Figures to be updated and refined.

Commented [MD43]: To be developed

It should be noted that these estimates are associated with significant uncertainties and ranges have been estimated. There are other potential economic costs and benefits that could not be quantified. Adjusting the potential restriction to minimise this is discussed further below.

Although alternatives are generally considered to be technically feasible in most applications (~~further testing is required for~~ large atmospheric storage tanks requiring more research and testing), there are also potential implications of the performance of alternatives in some cases, including slower fire suppression, and foams being less flexible and less easy to use. These have not been quantified. It should be noted that there was divergence in the stakeholder input about technical feasibility of alternatives. A few stakeholders have voiced concerns over the potentially reduced fire safety, at least in specific applications, and the associated risk of additional health, safety and economic (fire damage) impacts. However, our analysis has concluded that they are not the most likely outcome and that large atmospheric storage tanks are the main application for which there is still extensive further testing required.

However, since fluorine-free foams have characteristics which differ from PFAS-based foams, for each user, testing of the alternative foam product in conjunction with the foam application

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method and adaptation of the fire extinguishing installation and equipment will be required⁶⁹. For certain types of uses this transition is expected to be implementable in a relatively short term, whereas for other uses, a longer time is likely to be needed. In addition, the potential for emission reduction depends on the type of use. For these reasons, different transitional periods are considered per type of use and described below.

In order to maximise effectiveness while minimising potential adverse socio-economic impacts of a restriction, it appears appropriate to vary the specific conditions (particularly **transition periods**) by application and user sectors, because of their significant divergence in terms of the likelihood of emissions and implications of switching to alternative foams:

- **Training and testing** should be the highest priority for a quick transition to fluorine-free foams, because the use of alternatives is well established and already recommended as industry best practice. Training accounts for the majority of fire-fighting foam use (although likely not for the majority of PFAS emissions) and the potential for adverse socio-economic impacts is very low for training and testing.
- **Chemicals / petrochemicals** is the largest user sector meaning that the costs of transitioning but also the current risk of PFAS emissions are higher in total (although not necessarily higher per company, per turnover, etc.). However, longer transition periods may be needed for specific applications (notably large tank fires) where further testing is required to determine the technical feasibility of alternatives and potential fire-safety risks from using alternatives are high. Users have suggested a longer transition period of up to ~~40~~¹² years is required. This is the largest user sector, so in order to ensure effectiveness of the regulation in reducing PFAS-emissions, it seems appropriate that any longer transition period should be limited to the most sensitive applications within this sector, particularly large incidents and large atmospheric storage tanks. Further consideration of this would be needed in the consultation on any restriction proposal.
- For **small incidents as well as all other sectors**, shorter transition periods between 3-6 years have been suggested and are expected to minimise socio-economic implications of a restriction.
- Of these, in particular **marine applications, municipal fire services and ready to use applications** should be priorities for a quick transition. In marine applications the potential for retention of run-off and clean-up after incidents is particularly low, and alternatives are established. For municipal and ready to use applications, alternatives are well-established and these sectors may involve fire incidents outside of specific industrial sites where there is a risk that retention of run-off and clean-up after incidents are more difficult.
- In **civil aviation** a relatively quick transition could be sought as well, because alternatives are considered feasible and have successfully been implemented by many users⁷⁰. However the potential for retention of run-off and clean-up is relatively high, while there is the concern that, if the use of alternatives caused any increased fire-safety risks, the potential damages could be significant and would likely include danger to human life.
- Alternatives are less well established in the **military sector**, but they are considered by stakeholders to be feasible. Transition is probably possible but requires extra care because, if the use of alternatives caused any increased fire-

Commented [MD44]: To see if we propose 18 months or 5 years for marine. On one side you have the releases problem but on the other side the fire safety where on a boat you have little escape possibilities. Some claim that the alternatives are not fully ready yet.

⁶⁹ See section E.2.5.1. Technical feasibility

⁷⁰ No data on the exact number or market share was not available, but a list of examples that are mentioned in the literature/by stakeholders is provided in Section 2.7.1 above.

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safety risks, the potential damages could be significant and could include danger to human life. A relatively long transition period may be needed to allow for sufficient time for alternative products to gain the necessary certifications.

Regarding **concentration thresholds**, a balance would need to be struck between the amount of PFAS emissions remaining if a given threshold is adopted, versus the costs of cleaning imposed in order to achieve that threshold. Stakeholder input suggests that 100 ppb can be achieved with a relatively simple cleaning process (cost likely low but not quantified). Lower thresholds are achievable with more complex and costly processes. For instance, achieving 1 ppb could cost around €12,300 per appliance according to one estimate, which could imply EU total costs in the order of €1 billion. However, setting a lower concentration threshold would lead to a relatively small additional reduction in PFAS emissions, compared to the overall reduction achieved by the restriction. The average concentration of PFAS in PFAS-based fire-fighting foams is some 2-3%, ~~(mixed with water before application it is in the order of 0.5% (or 5 million ppb)). This means a reduction from 5 million ppb to 100 ppb would cover 99.998% of the initial emissions. A further reduction to 1 ppb would cover 99.99998% of the initial emissions (an additional 0.00198%).~~

Lastly, the restriction proposal suggests obligation to apply **fire management plans** and **best practice risk management measures** during and after the use of PFAS-based fire-fighting foam. This covers among others foam purchase, containment, treatment, proper disposal of foams and fire water run-off, use of personal protective equipment. These measures could provide relatively effective reduction of PFAS emissions and exposure of workers and professionals at relatively low cost during the transition periods when PFAS-based foams continue to be used.

Based on the above, the restriction proposal presented in the summary is proposed.

Commented [MD45]: To be updated with proposed threshold.

Annex A: Manufacture and uses

A.1. Manufacture, import and export

Commented [MD46]: Additional info on this will be added (contracted to Ramboll).

This study has focused on the use of PFAS in fire-fighting foams. The available data on the use of PFAS in fire-fighting foams and the sales and uses of these foams in the EU are described in detail in the following section. In personal communication, Eurofeu indicated that the manufacture of PFAS-based fire-fighting foams in the EU is similar to the sales. Hence, the quantity of PFAS-based fire-fighting foams manufactured in the EU is expected to be in a similar order of magnitude as the sales presented below (14,000-20,000 tonnes per year), while import and export are expected to be relatively small.

In their comment to the PFHxA restriction proposal⁷¹, the Firefighting Foam Coalition (FFFC) indicated that there are approximately 20-25 manufacturers of class B firefighting foams in the EU, selling products all over the world, in particular Africa, Asia and the Middle East. Their sales of foam and foam equipment worldwide are estimated in the range of € 120-150 million annually with foam agent sales accounting for about € 60-70 million of that total. Currently about 85- 95% of their class B foam sales are fluorinated foams.

According to Eurofeu (personal communication, 2021), several EU foam manufacturers have production facilities outside the EU. Therefore, a ban on the export of PFAS-based foams would affect some companies but not others. However, no specific numbers have been provided by Eurofeu.

A.2. Uses

A.2.1. Introduction

The main aim of this Section is to estimate the tonnages of fluorine-based and fluorine-free fire-fighting foams manufactured and placed on the market in the EU. The different functions (e.g. film-forming, surfactants, solvents) provided by different components of fire-fighting foams and the type of fires for which their use is recommended is also discussed. In addition, an overview of market data (and functions provided) for fluorine-free alternatives is also given, to support the analysis of alternatives and socio-economic impacts.

A.2.2. Tonnages of fluorosurfactants used in fire-fighting foams production

According to data provided by Eurofeu, five foam manufacturers representing approximately 60-70% of the EU market purchase approximately 335 tonnes of fluorosurfactants per annum in the EU (data collected in 2018). These data include 7 specific known fluoro-compounds and 3 unknown fluoro-compounds (see Table A.1). They are used to produce fire-fighting foam concentrates or liquid ready-for-use agents (pre-fill for fixed firefighting systems and/or portable extinguishers). According to the same Eurofeu data, the concentration of the fluoro-

⁷¹ Comment 3010 in Part 2 document available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

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compound in the fire-fighting foam concentrates range between 0.1% and 45% (no average value was given).

It should be noted that the identity of the substances with the largest tonnages was not specified in these data as the data were confidential. Based on the approximate share of the market reflected in these data, it is estimated that the total tonnage of fluorosurfactants used in fire-fighting foams in the EU is approximately 480-560 tonnes per year⁷². This is consistent with the total tonnage of PFAS-based fire-fighting foams estimated further below, and an average concentration of fluorosurfactants in the foams of around 2-3% (as suggested by various stakeholder responses to the consultation).

Table A.1 Tonnage of fluorosurfactants purchased for the production of fire-fighting foams by manufacturers participating in the 2018 Eurofeu survey

Fluoro-compound	CAS number	Tonnes per year	Share of the total market
1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt	34455-29-3	21.1	6%
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	80475-32-7	17.2	5%
2-methyl-2 - [(1-oxo-3 - [(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl) thio] propyl) amino] -1-propanesulfonic acid, sodium salt	62880-93-7	0.5	<1%
2-hydroxy-N,N,N-trimethyl-3-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-1-Propanaminium, chloride (1:1)	88992-45-4	0.2	<1%
2-Propenamide, telomer with 4-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-1-butanethiol)	unknown	0.2	<1%
2-Propenoic acid, telomer with 2-propenamide and 4-[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)thio]-1-butanethiol, sodium salt	unknown	0.3	<1%
2-Propenamide, telomer with 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanethiol	76830-12-1	0.9	<1%

⁷² According to Eurofeu, the data is expected to cover 60-70% of the EU market. The total market has been estimated by dividing 335 tonnes by 70% (lower end of range) and by 60% (upper end of range), respectively.

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Fluoro-compound	CAS number	Tonnes per year	Share of the total market
unknown C-6 fluorinated substances	unknown	17.1	5%
unknown 1	unknown	138.6	41%
unknown 2	unknown	138.6	41%
Total (2018 Eurofeu survey)		335	
Total EU market (extrapolated)		480-560 [1]	

Source: Wood 2019 based on data provided to the authors by Eurofeu.

Notes:

Substances marked as unknown have not been revealed by the individual manufacturers to preserve commercially sensitive information.

[1] According to Eurofeu, the data is expected to cover 60-70% of the EU market. The total market has been estimated by dividing 335 tonnes by 70% (lower end of range) and by 60% (upper end of range), respectively. Results were rounded to two significant figures.

A.2.3. PFAS-based fire-fighting foams

A.2.3.1. Sales of fire-fighting foams by user sector

Eurofeu also provided figures on the yearly sales of PFAS-based fire-fighting foams to various user sectors in Europe, based on a 3-year average (2016-2018). Six Eurofeu member companies⁷³ have provided data. In total, they sell 13,669 tonnes of PFAS-based fire-fighting foams per year. Of these, an estimated 8,200 are employed in fixed systems and 5,500 in mobile systems⁷⁴. The split by sector is detailed in Figure A.1 below. This shows that chemical/petrochemical is by far the largest user sector (59%), but municipal fire brigades, marine applications, airports and military applications also account for significant volumes⁷⁵. Ready-for-use products only account for a very small share of PFAS-based foams according to this data. The majority of this category are fire extinguishers although not all foam fire extinguishers use ready-for-use foams, according to personal communications with Eurofeu). However, some stakeholders have suggested that the number of fire extinguishers using PFAS-based foams could be significant. An estimate is provided in the following sub-section.

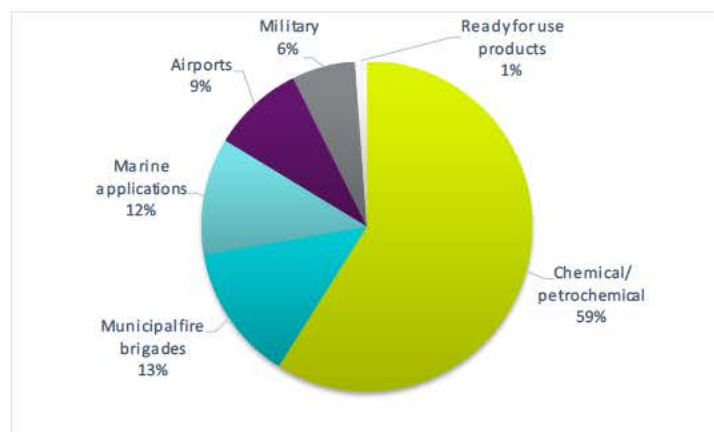
⁷³ STHAMER Hamburg, Auxquimia (Perimeter Solutions), Solberg Scandinavia, Dafo Fomtec, Orch dee, Johnson Controls (aka Tyco)

⁷⁴ The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split. The original values were 5,010 tonnes for fixed systems and 3,350 tonnes for mobile systems (total 8,360 tonnes).

⁷⁵ According to personal communication with Eurofeu, there is some uncertainty in the data available to foam manufacturers about the precise distinction between user sectors. This is because although certain products may be marketed primarily for a specific user sector, it is not always known to whom the products are ultimately sold through traders and vending companies, and what they ultimately use it for (particularly for large users active across several sectors). Generally "chemical/petrochemical" is expected to include offshore oil and gas platforms (in addition to refineries and other facilities storing, processing or transporting flammable liquids), while "marine applications" refers to the shipping industry. However, due to the above uncertainty some of the tonnage for marine applications may also reflect use in offshore oil and gas platforms.

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Figure A.1 Split of PFAS-based fire-fighting foams by sector



Source: Wood 2019 based on data provided to the authors by Eurofeu.

Eurofeu estimate that the data they provided based on an internal survey covers roughly 70% of the EU market. It is therefore estimated that the total annual EU use of PFAS-based fire-fighting foams could be in the order of 20 thousand tonnes⁷⁶.

A.2.3.2. Additional estimate of use in fire extinguishers

Three different sources for the number of fire extinguishers using PFAS-based fire-fighting foam in the EU were identified:

1. Eurofeu provided the European Commission with a position paper which estimates that there are approximately 76 million fire extinguishers in the EU, approximately 15 million of which use PFAS-based fire-fighting agents.
2. Through individual communication with TSF (a German consultancy specialised in firefighting services), it has been estimated⁷⁷ that, in the whole of the EU, between about 60 million and 90 million fire extinguishers using PFAS-based foam currently

⁷⁶ Calculated as 13,669 tonnes divided by 70% and rounded to the closest thousand tonne.

⁷⁷ The values have been extrapolated from data from bvfa - Bundesverband Technischer Brandschutz e. V. (German Federal Association of Technical Fire Protection) for fire extinguisher sold in Germany in 2016 as follows. Tonnages of major additional fire extinguisher manufacturers that are not part of bvfa have been added to the bvfa data by TSF. This yields the estimate that approximately 2,2 million fire extinguishers are sold every year in Germany, with an average lifetime of 20-25 years, which suggests that roughly 50 million units are currently present in Germany. Dividing this figure by the German population (82 million), a value of 0.6 fire extinguishers per capita is obtained. This value is then multiplied by the population of each country to estimate the number of fire extinguishers in each of them (population Netherlands: 17 m, population France: 67 m, population Belgium: 11,5 m, population United Kingdom: 60 m, population Ireland: 5 m, population Austria: 9 m, population Switzerland: 8,5 m, population rest of Europe: 500 m). Finally, the value obtained is multiplied by the share of PFAS foam-based fire extinguishers on the total of fire extinguishers in each country as estimated by TSF (Germany: 35%, Netherlands: 55%, France: 55%, Belgium: 45%, United Kingdom: 25%, Ireland: 25%, Austria: 45%, Switzerland: 45%, rest of Europe: 10%). This yields the following number of fire extinguishers using PFAS-based foam per country: Germany: 17 million units; Netherlands: 6 million units; France: 22 million units; Belgium: 3 million units; United Kingdom: 10 million units; Ireland: 1 million units; Austria: 2 million units; Switzerland: 2 million units; Rest of Europe: 30 million units.

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exist, but note that this is a high-level estimate based on extrapolation from German data and expert judgement, so the Eurofeu estimate is likely more accurate.

3. The REACH restriction proposal for PFHxA⁷⁸ states based on personal communication with one stakeholder and on data from the German Federal Association for Technical Fire Safety (bvfa), that in Germany roughly 600 000 hand held fire extinguishers containing AFFF are placed on the market per year, so it is possible that in Germany 6 - 12 million and EU-wide 40 - 80 million extinguishers are in use (i.e. in circulation in total rather than on an annual basis). Given the same underlying data source (bvfa) was used and similar results were obtained, it is likely that this is in fact the same estimation as source number 2 above, with slightly different assumptions.

Based on the figures above, the following estimates the total tonnage of PFAS-based fire-fighting foam in fire-extinguishers in circulation, as well as the annual tonnage placed on the market.

- The Eurofeu position paper quotes 6-9 litres as the typical size of a fire extinguisher. According to TSF (based on bvfa data), the size can range between 2 and 9 litres.
- Multiplication of 6-9 litres with the estimated 15 million fire extinguishers yields a range of 90-135 million litres (wider range: 30-810 million litres using 2-9 litres and 60-90 million fire extinguishers) of PFAS-based fire-fighting agents used in fire extinguishers. This would be equivalent to about 90,000-135,000 tonnes (wider range 30,000-810,000 tonnes)⁷⁹ of PFAS-based fire-fighting agents currently present in fire extinguishers in the EU, or ca 3,600-6,750 tonnes (wider range 1,200-35,000 tonnes) of PFAS-based fire-fighting agents sold in fire extinguishers in the EU annually⁸⁰.
- According to personal communication with Eurofeu, the PFAS-based fire-fighting agents in fire extinguishers are either foam concentrate already mixed with water, or a capsule of foam concentrate that is mixed with water when the extinguisher is triggered. That means that only a small share of the fire-fighting agent in the extinguisher is PFAS-based foam concentrate, and the concentration of PFAS in the fire-fighting agent is much lower (2-5g per 6-9 litre extinguisher, or 0.02-0.08%, according to the Eurofeu position paper) than for the foam concentrates discussed above. To make the 3,600-6,750 tonnes per year of PFAS-based fire-fighting agents in fire extinguishers comparable to sales of PFAS-based foam concentrates by sector (presented in the previous subsection), they need to be converted: Conservatively assuming that foam concentrates account for 10% of the fire-fighting agent for fire extinguishers would imply some 360-675 tonnes of PFAS-based foam concentrates are used annually in fire extinguishers in the EU⁸¹.

Lastly, to sense check this result, it is compared to the tonnage of ready-for-use products estimated in the previous sub-section:

- Based on Eurofeu data, it was estimated that the total annual EU use of PFAS-based fire-fighting foams in the EU is at least 14,000 tonnes but it could be up to around 20,000 tonnes. Figure A.1 (also based on Eurofeu data) puts the share of

⁷⁸ <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18323a25d>

⁷⁹ Assuming a density of approximately 1kg/l.

⁸⁰ Calculated by dividing the total tonnage present by the average lifetime of 20-25 years, as indicated by TSF.

⁸¹ Calculated as: 3,600 tonnes of PFAS-based fire-fighting agents * 10% = 360 tonnes of PFAS-based foam concentrate. Similarly for the higher end of the range 6,750 tonnes * 10% = 675 tonnes.

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ready-for-use products at 1%, so the annual tonnage of ready-for-use products is around 140-200 tonnes⁸².

- This is somewhat lower than the estimated 360-675 tonnes of PFAS-based foam concentrates used in fire extinguishers. However, the data appear to be consistent because Eurofeu specified that not all foam fire extinguishers are included in the category “ready-for-use foams”.
- Even if the share of ready-for-use products was higher than suggested by Eurofeu (Figure A.1), the total tonnage across all sectors would not be significantly affected by the addition of a few hundred tonnes of ready-to-use products, as it was only estimated at an accuracy in the order of magnitude of thousands of tonnes in this report.

A.2.3.3. Other information on tonnages from the consultation

The following additional information on tonnages was provided in the consultation:

- Additional fire-fighting foam manufacturers (not covered by Eurofeu’s internal survey) provided figures for three different products they manufacture where the PFAS Carboxymethyldimethyl-3-[[3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulphonyl]amino]propylammonium hydroxide (CAS number 34455-29-3) and 6:2 FTS are used (i.e. all three products use both substances combined). The three products are employed in different sectors:
 - The first is used by the respondents’ customers in airport and marine applications. Of this foam, 700,000 litres are manufactured/imported and 200,000 litres are sold in the EU every year.
 - The second is used in oil and gas, marine, chemistry and municipal fire fighters applications. 450,000 litres of this product are manufactured/imported in the EU and 250,000 litres are sold every year in the EU.
 - The third product is used in the oil and gas and marine sectors. 250,000 litres of this foam are manufactured/imported and 100,000 litres are sold every year in the EU.
 - These volumes are additional to the Eurofeu data presented above. The three foams in sum account for 550,000 litres of annual sales in the EU. Assuming a density of approximately 1kg/l, this would be equivalent to about 550 tonnes of foam that can be added to the Eurofeu total (but would already be included in the EU total extrapolated from Eurofeu data). However, given the exact sector split is not known, they have not been added to the sector breakdown.
- One respondent operating in the field of industrial safety, in particular dedicated to technical support and training, stated that they manufacture 5,000 litres per year of a foam containing a C6 fluorine compound, which is used only for training purposes. As above, this is additional to the Eurofeu data, but has not directly been added because the tonnage or density is not known,
- One respondent operating in the oil and gas sector provided figures for four fire-fighting foams they purchase; two of these contain poly(1,1,2,2-tetrafluoro-1,2-ethanediyl),alpha fluoro-omega-2-(3-((caboxylatomethyl)dimethylammonoi)propylaminosulfonyl)ethyl, whereas the other two contain different PFAS that have not been specified:

⁸² Calculated by multiplying the total tonnage of fire-fighting foams (14,000-20,000 tonnes) with the share of ready for use products (1%).

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- The two products containing poly(1,1,2,2-tetrafluoro-1,2-ethanediyl),alpha fluoro-omega-2-(3-((caboxylatomethyl)dimethylammonoi)propylaminosulfonyl)ethyl are used in the offshore oilrig and refinery sectors for spills⁸³, accidents and function tests in process plant fires and trainings. They purchase less than 5 tonnes per year of each of these foams and employ less than 5 tonnes in each instance of use.
- The third product is used in the offshore oil and refinery sectors in cases of spills, accidents and function tests in alcohol fires. Similarly to the previous, less than 5 tonnes are bought every year and less than 5 tonnes are employed in each instance of use.
- A volume between 30 tonnes and 70 tonnes of a fourth product is purchased every year by the respondent, but no other details have been provided regarding the use of this foam.
- One respondent operating in industrial safety for the oil refineries, chemicals and petrochemicals sectors provided figures for one foam based on the C6 fluorine compound, which is used for training exercises on large hydrocarbon fires. They purchase 5 tonnes per year of this product and typically employ it 100 days a year.
- Another respondent operating in the oil refineries, chemicals and petrochemicals sectors provided figures for one product they purchase, which can be used for almost all class B fires. They purchase between 20 and 60 tonnes per year of this foam and in 75% of cases, fires are extinguished with less than 400 litres of foam concentrate.

Respondents quoted prices for PFAS-based fire-fighting foams in the range from €2 to €30 per litre for concentrates. For those PFAS based fire-fighting foams for which data on tonnage and price is available, the weighted average price is around €3 per litre, but note that these products reflect only a small share of the total market, so this estimate is uncertain. Some consultation responses suggest that generally speaking, foams providing a higher performance often contain a higher concentration of PFAS which is associated with a higher cost.

A.2.3.4. Number of sites using fire-fighting foams

No specific data on the number of sites using fire-fighting foams (PFAS-based or fluorine-free) was available. However, in order to estimate the order of magnitude of user sites, the total number of sites in some of the of the main user sectors can be considered:

- Chemicals/petrochemicals: There are over 10,000 establishments covered under the EU's Seveso III Directive⁸⁴. One of the main accident scenarios linked to most Seveso-regulated substances is related to fires. Many other facilities with flammable fuels and chemicals below the Seveso Directive thresholds will also require firefighting equipment.

⁸³ AFFF are in some cases also used as prevent on in spills that have not (yet) caught fire. See for instance: <https://www.nrl.navy.mil/accomplishments/materials/aqueous-film-foam>

⁸⁴ Analysis and summary of Member States' reports on the implementation of Directive 96/82/EC on the control of major accident hazards involving dangerous substances, Final report, <https://op.europa.eu/en/publication-detail/-/publication/26c9aa63-523e-11e7-a5ca-01aa75ed71a1>.

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- Marine applications: Over 1,200 commercial seaports operate in the EU⁸⁵ and Europe's maritime traffic is responsible for some 15,000 seagoing vessels⁸⁶.
- Airports: There are 401 commercial airports in the EU-28⁸⁷, many of which will have multiple fire-fighting foam storage/use equipment.
- Municipal fire brigades: There are over 50,000 public fire brigades in the EU, excluding those covering airports and private brigades covering industrial risks⁸⁸.
- Military: In the European Economic Area, there are about 239 military airbases.

Based on the above, there are likely to be several tens or potentially hundreds of thousands of facilities using (or at least possessing) fire-fighting foams. In addition, there are likely many other sites possessing fire-extinguishers using fire-fighting foams.

A.2.3.5. Conclusions of the market analysis for PFAS-based fire-fighting foams

In conclusion, based on information provided by Eurofeu and additional manufacturers, it has been estimated that at least 14,000 tonnes, but probably around 20,000 tonnes of PFAS-based fire-fighting foams are sold in the EU annually. The main application is the chemical and petrochemical industry, which employs 59% of these foams. This is followed by municipal fire brigades, marine applications, airports and the military. The foams are used in fire incidents, spills, tests and training exercises.

There are likely several tens or potentially hundreds of thousands of facilities using (or at least possessing) fire-fighting foams, not counting those only using fire-extinguishers. Prices for PFAS based fire-fighting foams range from €2 to €30 per litre for concentrates, with the average estimated at around €3 per litre (subject to significant uncertainty).

A.2.3.6. Functions provided in the foams and types of fires the foams are used for

According to the consultation, the PFAS-based fire-fighting foams find application in a broad range of sectors, such as aviation, marine, oil and gas, offshore oil, refineries, chemicals and railways⁸⁹.

The main function of the PFAS contained in the foam is to act as a surfactant, i.e. to form a film over the burning liquid surface in order to prevent flammable gases from being released from it. PFAS foams generate an aqueous film, i.e. a thin layer of water floating on top of the lighter non-water miscible liquid⁹⁰, which is a key feature provided by fluorosurfactants (these foams are generally called "AFFF" for "Aqueous film-forming foams"⁹¹). The stable foam

⁸⁵ European Commission (2013): Europe's Seaports 2030: Challenges Ahead. Available at : https://ec.europa.eu/commission/presscorner/detail/en/MEMO_13_448.

⁸⁶ In early 2019, the total world fleet stood at 95,402 ships. Europe accounted for 16% of container port traffic (as a proxy for the share of global vessels relevant to Europe). Source: UNCTAD Review of Maritime Transport 2019. Available at https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf.

⁸⁷ Eurostat: Number of commercial airports (with more than 15,000 passenger units per year) [avia_if_arp], Data for 2017.

⁸⁸ FEU statistics, <https://www.f-e-u.org/career2.php>

⁸⁹ A respondent responsible for railway maintenance stated that PFAS-based foams are used in railways; the use of fire-fighting foams is particularly relevant for fire-protection in railway tunnels. The reason is that railways can carry various chemicals and other dangerous goods and, if they catch fire in tunnels, it is particularly critical and fires can be much more difficult to extinguish.

⁹⁰ Water has a higher specific gravity compared to most hydrocarbon liquids, hence sinks if applied onto them.

⁹¹ Another type of aqueous film forming foam agents are FFFP – film forming protein foams – which use protein hydrolysates as the foaming compound instead of carbon hydrate surfactants. Both types are available also as alcohol resistant versions: AFFF-AR and FFFP-AR.

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blanket formed enables the sealing of the flammable liquid surface, impeding the release of flammable gasses with the ambient air. PFAS surfactants in the firefighting foams also prevent the emulsification of the hydrocarbon liquid with the foam, even for water-miscible hydrocarbon liquids such as alcohols, avoiding therefore the risk of fuel pick-up, which would alter the foam structure and make it flammable. AFFF have been considered very effective and also very forgiving with respect to application, proportioning and foam expansion. They allow the use of specific techniques such as sub-surface injection in non-water-miscible flammable liquids, application at very low expansion ratios (e.g. delivered by sprinklers, hollow-jet nozzles, non-aspirated hand lines and monitors) or forceful applications. Overall, AFFF made firefighting foams easy to use at a very high level of reliability and performance (Eurofeu 2019⁹²)

This is a-These are particularly relevant features that enables applications in industrial fires - for example tank fires, where large quantities of flammable liquid are stored. They are used for training purposes and in a variety of fire incidents, from small fires to the above-mentioned large tank fires, and can be applied both with mobile and ~~semi~~-stationary equipment.

According to Eurofeu (Eurofeu, 2019) AFFF are still amongst the first-choice agents for scenarios where the foam needs to be applied over certain distance (vertical and/or horizontal) onto liquid fuel having a certain depth (like large tank farms of flammable liquids). On fires of shallow fuel spills, emulsification does not play a major role in overall fire performance of the foam agent because there is not enough fuel depth for the foam to sink in. These fires (e.g. damaged cars or even road tankers) likely may not require an AFFF. Similarly, municipal firefighting, fires of solid combustibles (so called "Class A-fires") and fires of melting fuels (solid materials becoming liquid due to heat, such as plastics, fats and waxes) do not require AFFF, the latter fire risks being able to be addressed with modern high performing fluorine free foam agents.

A.2.4. Fluorine-free alternatives

A.2.4.1. Sales of fire-fighting foams by user sector

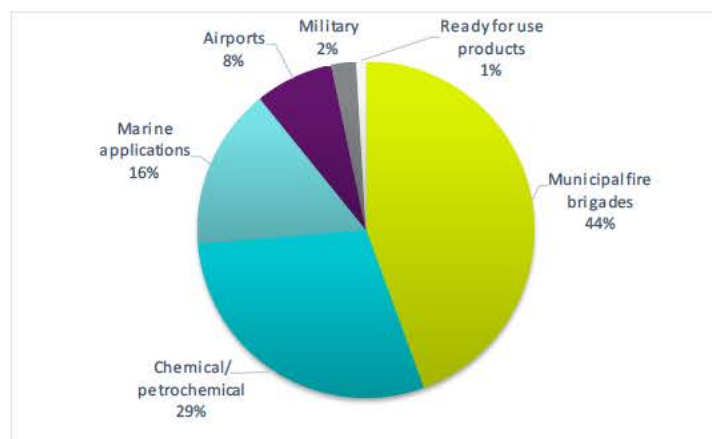
Consultation with Eurofeu provided figures on the yearly consumption of fluorine-free firefighting foams in various sectors in Europe, based on a 3-year average (2016-2018), highlighting a total use of 6,553 tonnes per year. Of these 6,553 tonnes, 2,134 are utilised in fixed systems and 4,418 in mobile systems⁹³. The split by sector is detailed in Figure A.2 below. Notably, it varies considerably from that of PFAS-based foams, with a much larger share used by municipal fire brigades but a much smaller share in the chemical/petrochemical sectors.

⁹² Eurofeu, 2019 - [Pos t on Paper on Fluorine containing firefighting Foams - Responsible Use of AFFF and the likes](#)

⁹³ The number of companies that provided a response on whether the foams are used in fixed or mobile systems is lower than those that provided a response for the sectoral overview, therefore in the original data the total tonnage of the former is lower than the latter. To fill this gap, the tonnages for both fixed and mobile systems have been inflated so that their total matches the total in the sectoral split. The original values are 1,259 tonnes for fixed systems and 2,605 tonnes for mobile systems (total 3,864 tonnes).

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Figure A.2 Yearly use of fluorine-free firefighting foams by sector.



Source: Data provided to the authors by Eurofeu.

Notes: The majority of the 'ready for use products' are fire extinguishers. However, not all foam fire extinguishers use ready-for-use foams.

Eurofeu estimate that the data they provided based on an internal survey covers roughly 70% of the EU market. It is therefore estimated that the total EU use of fluorine-free fire-fighting foams could be in the order of 9 million tonnes⁹⁴.

A.2.4.2. Other information on tonnages from the consultation

The following information on tonnages was provided in the consultation. Information on which chemical group of alternatives (based on the grouping established in the substance identification, see Section B.1.) is also listed.

- Additional fire-fighting foam manufacturers (not covered by Eurofeu's internal survey) stated that they manufacture/import a total of 1,250,000 litres and sell 380,000 litres of PFAS-free foams (based on hydrocarbon surfactants) per year in the EU. Assuming a density of approximately 1 kg/l, this would be equivalent to about 380 tonnes of foam that can be added to the Eurofeu total (but would already be included in the EU total extrapolated from Eurofeu data). However, given the exact sector split is not known, they have not been added to the sector breakdown.
- One respondent operating in fire protection for oil refineries/storage, chemicals, petrochemicals and municipalities provided figures for three types of fluorine-free foams (chemical groups of alternatives unknown) used for different purposes:
 - The first is used by the respondent for exercise and testing of fixed systems (i.e. not for fire-fighting), about 12-20 times per year at 300-10,000 kg per use. They purchase 15,000-30,000 kg of this foam per year.

⁹⁴ Calculated as 13,669 tonnes divided by 70% and rounded to the closest million tonnes.

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- The second is used by the respondent for testing of proportioning systems (i.e. not for fire-fighting), typically 4-6 times per year, with 1,000-6,000 kg used in each instance. They purchase 10,000 kg of this product per year.
- The third was due to start testing in autumn 2019, therefore they did not yet have any experience on real fires with this foam. It is expected that this product will be used about 50 times per year, with 1-400 kg used in each instance.
- One respondent operating in the field of industrial safety, particularly dedicated to technical support and training, provided figures for two different fluorine-free foams, both used for training purposes:
 - The first (a product shown to contain detergents according to the substance identification task) is used by the respondent for hydrocarbon fires in the oil and gas sector, with a typical frequency of 150 days per year. They purchase 4,000 kg of this product per year.
 - The second (chemical group of alternatives unknown) is used by the respondent for alcohol fires, about 30 days a year. They purchase 1,000 kg of this foam per year.
- One respondent providing training in the safety sector gave figures for one type of fluorine-free foam (a product shown to contain detergents according to the substance identification task). This is used only for training purposes on fires of different sizes and in various sectors, such as airports, oil and gas and marine. They purchase 1,200 kg of this product a year and typically use it around 4 hours per week, depending on the training activity.
- One respondent active in the airport sector provided figures for one fluorine-free foam (a product shown to contain hydrocarbon surfactants and detergents according to the substance identification task), which is used for all aircraft applications and training activities. They purchase 3,600 litres of this foam a year. Approximately 300 litres are used each month, with a typical use of 15 minutes per month.
- Another respondent working in the airport sector stated that they purchase 5,000 litres per year of a fluorine-free foam (chemical group of alternatives unknown), which is used only for training and system testing.
- Additional respondents have stated they use fluorine-free foams based on hydrocarbon surfactants and detergents in aviation, offshore oil installations and onshore terminals and refineries, without specifying quantities.

Respondents quoted prices for fluorine-free foams ranging from €0.7 to €10 per litre. For those fluorine-free fire-fighting foams for which data on tonnage and price is available, the weighted average price is around €3 per litre, but note that these products reflect only a small share of the total market, so this estimate is uncertain. Although the range is lower and the average is similar to prices of PFAS-based foams (see above), some respondents suggested that fluorine-free foams are around 50% more expensive than comparable foams containing fluorine. However, fluorine-free foams are still predicted to have a growing presence on the market, due to increasing regulations/controls on fire-fighting training and testing.

A.2.4.3. Conclusions of the market analysis for fluorine-free alternatives

Based on information provided by Eurofeu and additional manufacturers, it has been estimated that at least some 7,000 tonnes, but probably around 9,000 tonnes of fluorine-free firefighting foams are sold in the EU annually.

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A breakdown by chemical group of alternatives (based on the grouping established in the substance identification) is not available, but consultation responses suggest that the main alternatives used are based on hydrocarbon surfactants and detergents.

The split by sector of use varies considerably from that of PFAS-based foams, with a much larger share used by municipal fire brigades but a much smaller share in the chemical/petrochemical sectors.

Prices for fluorine-free foams range from €0.7 to €10 per litre, with the average estimated around €3 per litre (subject to significant uncertainty).

A.2.4.4. Functions provided in the foams and types of fires the foams are used for

The fluorine-free fire-fighting foams considered in this analysis are specifically those that can potentially be used as alternatives to the PFAS-based foams. As such, they are potentially used in the same applications. The consultation responses specifically indicated that fluorine-free alternatives are currently used for training, process fires, alcohol fires and fuel fires, as well as for testing proportioning systems and are applied both with fixed and mobile equipment. When it comes to the application of the products, no significant differences between fluorine-based and non-fluorine foams have been highlighted from a market perspective, but this is analysed in more detail in the analysis of alternatives (see Section E.2.).

The substance identification (Section B.1) identified the following groups of substances that PFAS-free fire-fighting foams are based on: hydrocarbons, siloxanes, protein foams, detergents. All of these groups largely mimic the function of fluoro-surfactants in the PFAS-based fire-fighting foams, for instance hydrocarbon foams use hydrocarbon surfactants⁹⁵, siloxanes are also primarily used in fire-fighting foams to function as surfactants⁹⁶ and detergents are by definition surfactants.

A.3. Uses advised against by the registrants

The analysis in this Annex-XV dossier is based on substances that have been identified as being used in fire-fighting foams.

No review of registration dossiers for all of the potentially relevant PFAS substances has been undertaken in terms of identifying any specific uses that are advised against by the registrants.

⁹⁵ See for example: <https://www.fomtec.com/fluorine-free/category38.html> or <https://www.chemguard.com/about-us/documents-library/documents/Martin2009ReebokEcoguardpresentation2010-10-11.pdf>.

⁹⁶ See for example: <https://www.nfpa.org/-/media/Files/News-and-Research/Resources/Research-Foundation/Symposia/2016-SUPDET/2016-Papers/SUPDET2016Hetzer.ashx?la=en>.

Annex B: Information on hazard and risk

B.1. Identity of the substance(s) and physical and chemical properties

The objective of this section is to identify the PFAS (including long and short chain, their salts and precursors, intentionally used or as impurities) present in fire-fighting foams, the constituents of the fluorine-free fire-fighting foams and any non-PFAS fluorinated alternatives (if they exist).

In the following, the approach is briefly described (this Section). Then, results are discussed in Section B.1, in separate sub-sections first for alternatives to PFAS in fire-fighting foam that are fluorinated (but not based on PFAS), then for completely fluorine-free alternatives, and lastly for PFAS used in fire-fighting foams.

The substance identification was based on desktop research covering:

- Literature research based on:
 - Scientific peer reviewed literature (pubmed, google scholar);
 - Reports or other publications by national and regional environmental agencies; and
 - Reports or other publications by NGOs.
- Information gathered in the framework of regulations:
 - REACH (for example RMOAs, Annex XV restriction reports, RAC & SEAC documents of PFAS substances);
 - Stockholm convention (for example risk management evaluation, AoA reports, technical paper on the identification and assessment of alternatives); and
 - Basel convention(technical guidelines).
- Safety Data Sheets ((M)SDS) and any other information of known producers/associations;
- Environmental and human (bio-)monitoring data and case studies; and
- Expert knowledge (international experts).

In general, all the above-named documents were screened by using the following search terms: fire, foam, fluor and/or alternative. More specifically, in case the documents covered the analysis of alternatives (e.g. documents by REACH, Stockholm and NGOs) the documents were screened using the search terms fire and foam. This strategy was also undertaken in the screening of more general reports, for example those reports that cover PFAS in general. These kinds of reports were mostly published by environmental agencies.

In cases where analytical measurements were reported (case studies, (bio-) monitoring and scientific publications) it was made sure, that an unambiguous assignment to the usage of fire-fighting foam could be made. Only in cases where this was possible, the respective data was extracted.

A different strategy was elaborated for (M)SDS, in this case only the term “fluor” was used.

More detail about the specific search terms applied and the specific documents screened is provided alongside the results in the following sub-sections.

A matrix was created to collect all potentially relevant information from the literature review, but the identified information is summarised in the following.

B.1.1. Name and other identifiers of the substance(s)

B.1.1.1. Substance identification non-PFAS fluorinated alternatives

Due to concerns about their toxicity and regulatory pressure, long chain PFAS (such as C8, see definition later in this section) have been widely replaced by (perceived safer) alternative substances starting from the early 2000s. These alternatives include short-chain substances like C6 fluorotelomer based fluorosurfactants⁹⁷, but also non-fluorinated substances.

The knowledge of the chemical identity of these substances is currently very limited. As reflected in the Terms of Reference of this project, it is clear that a variety of PFAS and fluorine free-substances are used in fire-fighting foams, but it is not certain if there are any non-PFAS but fluorinated substances that have been or are still being used in fire-fighting foams.

The distinction between PFAS and non-PFAS fluorinated substances is the following: PFAS are a fully (per) or partly (poly) fluorinated carbon chain that "contain one or more C atoms on which all the hydrogen atoms are substituted (present in the non-fluorinated analogues from which they are notionally derived) by F atoms, in such a manner that they contain the perfluoroalkyl moiety (C_nF_{2n+1}-)." (OECD 2018). Non-PFAS fluorinated substances do not exhibit this particular feature of having "one or more C atoms on which all the H- are substituted by F-atoms". An example for this substance group are silicon dioxide molecules which are perfluorinated. These substances might be used in textiles as an alternative to PFAS⁹⁸. Based on the length of the fluorinated carbon chain, short and long chain PFASs can be distinguished.

Long chains refers to:

- Perfluorocarboxylic acids (PFCAs) with carbon chain lengths C8 and higher, including perfluorooctanoic acid (PFOA);
- Perfluoroalkane sulfonic acids (PFASs) with carbon chain lengths C6 and higher, including perfluorohexane sulfonic acid (PFHxS) and perfluorooctane sulfonate (PFOS); and
- Precursors of these substances that may be produced or present in products.

To identify any potential non-PFAS fluorinated substances used in fire-fighting foams, a literature research in pubmed and google scholar was undertaken, using the following search terms:

("substance" OR "chemical" OR "compound") AND ("fire fighting foam" OR fire-fighting "fire fighting")

As of April 2019, the pubmed search returned 53 hits. However, the relevant hits covered only poly- and perfluorinated compounds. The same result has been found using google scholar.

SDS/supplier information, monitoring data, EPAs, NGOs, case studies and legislation were also screened for information on non-PFAS fluorinated substances (simultaneously with the screenings for information on the substance identity of PFAS- and fluorine free-chemicals, discussed below). No non-PFAS fluorinated substances could be identified.

In conclusion, the analysis suggests that fluorinated non-PFAS alternatives in the area of fire-fighting foams do not exist. This was confirmed in personal communication by Zhanyun Wang

⁹⁷ Fluorosurfactants are synthetic organofluorine compounds with multiple fluorine atoms. They can be fluorocarbon-based or polyfluorinated (Lehmle, 2005).

⁹⁸ <https://greensciencepolicy.org/wp-content/uploads/2015/04/Presentation-Stefan-Posner-PFAS-April-2015.pdf>

(ETH Zürich), an international expert on PFAS chemicals. It was also discussed and not disputed at the project workshop.

B.1.1.2. Substance identification - FFF (fluorine-free foams)

Because of regulatory pressure and consumer preferences for fluorine-free replacements, a lot of producers of PFAS-containing foams have introduced fluorine-free alternatives. Most of the foams are advertised as intended for use on class B hydrocarbon fuel fires such as oil, diesel and aviation fuels as well as class A fires such as wood, paper, textiles etc.

As explained above, various information sources have been reviewed in order to identify any relevant alternative to PFAS in fire-fighting foams. Many of these sources did not provide chemical names or/and CAS/EC numbers. In a lot of sources (e.g. from NGOs, ECHA and Stockholm Convention documents), only very general hints on replacement substances or substance groups have been identified. This includes the naming of the following substance groups:

1. Hydrocarbons;
2. Detergents;
3. Siloxanes; and
4. Protein foams.

However, more specific information on substances in FFF was identified in SDS and/or supplier information, some reports published by national authorities, and some peer-reviewed publications. Most relevant information was identified in SDS. As an additional source patents were considered using the google patent search. The results were in most cases the same as for the SDS.

A report by the Swedish chemicals agency (KEMI) compiles available knowledge about fire-fighting foams that were available on the Swedish market in 2014, with respect to chemical content, use, handling and disposal⁹⁹. Scientific peer-reviewed publications by Hetzer et al. highlighted various sugar-based siloxanes (Hetzer, R. et al. ; Hetzer, R. et al. 2014; Hetzer, R. H. und Kümmerlen 2016; Hetzer, R. H. et al. 2015). However, to our knowledge no CAS-numbers are available for these chemical compounds.

In the following, the identified substances are presented in more detail. In general, AFFF concentrates are themselves mostly water, with other components such as surfactants, solvents and stabilisers. The lowering of surface tension to allow formation of foam and hence a blanket over the source of fuel, may be accomplished by use of both fluorocarbon and hydrocarbon surfactants. In this context, some of the substances identified in this task are not believed to be direct PFAS- replacements in terms of being a surface active agent¹⁰⁰. In the following, only those substances which were identified by their chemical structure as replacements (R) for PFAS are discussed. It is also possible that some of the identified substances may need to be combined with other substances (for example a hydrocarbon in combination with a detergent) in order to fulfil their capacity as a PFAS-replacement.

However, it should be noted that their suitability as alternatives to PFAS-based fire-fighting foams is discussed in more detail in the analysis of alternatives (Section E.2.).

⁹⁹ <https://www.kemi.se/global/pm/2015/pm-6-15.pdf>

¹⁰⁰ Those substances are for example antimicrobial agents that are needed for the biological stability of the foam.

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For a better overview, the substances were grouped in the following substance groups: hydrocarbons, siloxanes, protein foams and detergents based on expert judgement.

Hydrocarbons

In terms of hydrocarbons, a variety of different substances/substance groups were found. This includes for example various fatty acids, xanthan gums, sugars, alcohols, PEGs and alkanes. These substances are found in a variety of different products from different manufacturers. In the following table more information on this is given. This includes the CAS/EC identifier, the substance name, the chemical group, the supplier and respective product name. The chemical group was assigned based on the authors' knowledge and presented and not disputed at the stakeholder workshop".

Table B.1 Identified hydrocarbons (identified by CAS) incl. CAS/EC identifier, the substance name, chemical group and the supplier and/or product name

CAS	EC	Substance name	Chemical group	Supplier and Product Name
500-344-6	157627-94-6	Alcohols, C10-16, ethoxylated, sulfates, triethanolammonium salts	Alcohols	N/A (identified via ECHA's dissemination website)
939-523-2		Alcohols, C8-10, ethoxylated, sulfates, sodium salts	Alcohols	N/A (identified via ECHA's dissemination website)
112-53-8	203-982-0	1-Dodecanol	Alcohols	Respondol ATF 3-6%: Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) LS xMax: Dafo Fomtec AB STHAMEX® 2% F6 Multi-purpose detergent foam: [REDACTED] STHAMEX-SV/HT 1% F-5 #9142: [REDACTED]
112-72-1	204-000-3	Tetradecanol	Alcohols	Respondol ATF 3-6%: Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) LS xMax: Dafo Fomtec AB STHAMEX® 2% F6 Multi-purpose detergent foam: [REDACTED] STHAMEX-SV/HT 1% F-5 #9142: [REDACTED]
160901-27-9	500-464-9	Alcohols, C9-11, ethoxylated, sulphates, ammonium salts	Alcohols	OneSeven of Germany GmbH. OneSeven Foam Concentrate Class A
67762-19-0	500-172-1	Alcohols, C10-16, ethoxylated, sulfates, ammonium salts	Alcohols	Kempartner AB: Meteor Allround Ma-13
67762-41-8	272-490-6	tetradecan-1-ol	Alcohols	Angus Fire: Expandol (aka Expandol 1-3), Expandol LT (aka Expanol 1-3LT)
68131-39-5	500-195-7	Alcohols, C12-15, ethoxylated	Alcohols	Verde Environmental Inc (Micro Blaze): Micro-Blaze Out
266-929-0	67701-05-7	Fatty acids, C8-18 and C18-unsatd.	Fatty Acid/oil	N/A (identified via ECHA's dissemination website)

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CAS	EC	Substance name	Chemical group	Supplier and Product Name
11138-66-2	234-394-2	Xanthan gum	Gum	Auxquimia: Phos-Chek 3x6 Fluorine Free (aka UNIPOL-FF 3/6); Phos-Chek Training Foam 140 [REDACTED] Moussol-FF® 3/6 FireRein: Eco-Gel Kempartner AB: Unifoam Bio Yellow Verde Environmental Inc (Micro Blaze) : Micro-Blaze Out
9000-30-0	232-536-8	Cyamopsis gum; Cyanopsis tetragonoloba	Gum	FireRein: Eco-Gel
9005-25-8	232-679-6	Starch	Hydrocarbon	Solberg: US20080196908
120962-03-0	601-748-6	Canola Oil	Oil	Eco-Gel; FireRein
25322-68-3	500-038-2	Poly(oxy-1,2-ethanediyl), α -hydro- ω -hydroxy- Ethane-1,2-d ol, ethoxylated	Polyethylene glycol	Dafo Fomtec AB: Fomtec AFFF 1% F, Fomtec AFFF 3% S, Fomtec AFFF 3%
27252-80-8	608-068-9	ALLYLOXY(POLYETHYLENE OXIDE), METHYLETHYL ETHER (9-12 EO)	Polyethylene glycol	1% AFFF Denko 3% AFFF Denko 6% AFFF Denko Alcohol AFFF 3% - 6% Single or Double Strength Denko
32612-48-9	608-760-0	Poly(oxy-1,2-ethanediyl), α -sulfo- ω -(dodecyloxy)-, ammonium salt (1:1)	Polyethylene glycol	Orchidee Fire: Orch dex BlueFoam 3x3
73665-22-2	616-006-7	Poly(oxy- 1,2-ethanediyl), .alpha.-sulfo.-omega.-hydroxy-C6-10-alkyl ethers, sodium salts	Polyethylene glycol	[REDACTED] STHAMEX® 2% F6 Multi-purpose detergent foam, STHAMEX® 3% F6 Multi-purpose detergent foam, STHAMEX® K 1% F-15 #9143,STHAMEX-SV/HT 1% F-5 #9142, TRAINING FOAM-N 1% F-0 #9141
96130-61-9	619-194-9	Poly(oxy-1,2-ethanediyl), α -sulfo- ω -hydroxy-, C9-11-alkyl ethers, sodium salts	Polyethylene glycol	Dafo Brand AB: ARC Miljö Dafo Fomtec AB: Fomtec AFFF 1% A, Fomtec AFFF 1% F, Fomtec AFFF 1% Plus, Fomtec AFFF 1% Ultra LT, Fomtec AFFF 3%, Fomtec AFFF 3%ICAO, Fomtec AFFF 3% S, , Fomtec Askum
308-766-0	98283-67-1	undecyl glucos de	Sugar	N/A (identified via ECHA's dissemination website)
439-070-6	439-070-6	(2R,3R,4S,5S)-2,3,4,5-tetrahydroxyhexanal (2R,3S,4R,5R)-2,3,4,5,6-pentahydroxyhexanal (2S,3S,4S,5R)-2,3,4,5-tetrahydroxy-6-oxohexanoic acid acetic acid calcium dihydride hydrate magnesium dihydride potassium dihydride sodium hydride	Sugar	N/A (identified via ECHA's dissemination website)
110615-47-9	600-975-8	Alkylpolyglycos de C10-16	Sugar	Orchidee Fire: Orch dex BlueFoam 3x3

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CAS	EC	Substance name	Chemical group	Supplier and Product Name
54549-25-6	259-218-1	(3R,4S,5S,6R)-2-(decyloxy)-6-(hydroxymethyl)oxane-3,4,5-triol	Sugar	Unifoam Bio Yellow
68515-73-1	500-220-1	Alkyl polyglucoside	Sugar	Dafo Brand AB: ARC Miljö Dafo Fomtec AB: Enviro 3x3 Plus, Enviro 3x3 Ultra, Enviro 3x6 Plus, Environ 6x6 Plus, LS aMax, MB -20, Trainer E-lite, Fomtec AFFF 1% A, Fomtec AFFF 1% F, Fomtec AFFF 1% Plus, Fomtec AFFF 1% Ultra LT, Fomtec AFFF 3% ICAO, Fomtec AFFF 3% S, Fomtec AFFF 3% OneSeven of Germany GmbH: OneSeven @ Foam Concentrate Class B-AFFF vs FOCUM: Silvara APC 3x6
N/a	917-341-4	Alkyl polyglucoside	Sugar	Solberg: US20080196908

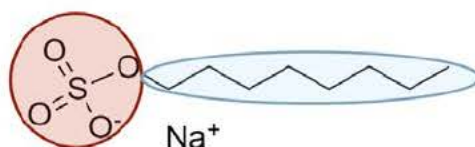
Detergents

Chemically, **detergents** belong to the group of hydrocarbons, however in the context of this project this substance group is considered separately. This group is characterised by their amphiphilic nature, being partly hydrophilic (polar) and partly hydrophobic (non-polar). The polar headgroup is needed to ensure their action on surfaces/interfaces (formation of micelles, lowering of the surface tension of water). The substances identified in this group, cover various alkanes that differ in the carbonic chain length (e.g. decyl, lauryl) and the head group (e.g. betaine, sulphates, amido betaines, triethanolamines). A betaine is a quaternary ammonium compound having three methyl groups.

This pattern is to some extent similar to those of the poly- and perfluorinated substances, in which an F-atom replaces the H-atom. In Figure B.1 sodium octyl sulphate is shown, this substance has been identified in at least ten individual products from several suppliers as an alternative to PFAS substances. The polar head group is highlighted in red and the non-polar alkaline chain is highlighted in blue.

It should be noted, that also PFAS-containing AFFF may also contain some of these detergents (for example STHAMEX® -AFFF 3%).

Figure B.1 Chemical structure of sodium octyl sulphate



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Table B.2 Identified detergents (identified by CAS) incl. CAS/EC identifier, the substance name, chemical group and the supplier and/or product name

CAS	EC	Substance name	Chemical group	Supplier and Product Name
308062-28-4	608-528-9 / 931-292-6	Amines, C12-14 (even numbered) - alkyl dimethyl, N-ox des	Alkylamine	Dafo Fomtec AB: Enviro 3% ICAO, Enviro USP vaPUREx LV 1% F-10 #7141
68155-09-9	268-938-5	Amides, coco, N-(3-(dimethylamino)propyl), N-ox des	Alkylamine	Angus Fire: Syndura (6% fluorine free foam)
70592-80-2	274-687-2	Amines, C10-16-alkyl dimethyl, N-ox des	Alkylamine	Angus Fire: Syndura (6% fluorine free foam)
269-087-2	68187-32-6	l-Glutamic acid, N-coco acyl derivs., monosodium salts	Alkylamine	
1469983-49-0	939-455-3	1-Propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-(C8-18(even numbered) acyl) derivs., hydroxides, inner salts	Alkylbetaine	Dafo Fomtec AB: Enviro 3x3 Plus, Enviro 3x3 Ultra, Enviro 3x6 Plus, Environ 6x6 Plus, LS aMax, Silvara APC 1
147170-44-3	604-575-4 / 931-333-8	1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-, N-(C8-18(even numbered) and C18 unsaturated acyl) derivs., hydroxides, inner salts	Alkylbetaine	MOUSSOL®-FF 3/6 F-15 #7941
61789-40-0	931-296-8	1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-, N-(C12-18(even numbered) acyl) derivs., hydroxides, inner salts	Alkylbetaine	OneSeven of Germany GmbH: OneSeven Foam Concentrate Class A Solberg: Solberg Patent US20080196908
64265-45-8	264-761-2	N-(2-hydroxyethyl)-N-[2-[(1-oxooctyl)amino]ethyl]-β-alanine	Alkylbetaine	vs FOCUM: Silvara APC 1, Silvara APC 3x3, Silvara APC 3x6, Silvara ZFK (0.5%)
68139-30-0	268-761-3	Cocam dopropyl hydroxysultaine	Alkylbetaine	Solberg: US20080196908
13150-00-0	236-091-0	Sodium 2-[2-[2-(dodecyloxy)ethoxy]ethoxy]ethyl sulphate	Alkylsulfate	Kempartner AB : Unifoam B o Yellow

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CAS	EC	Substance name	Chemical group	Supplier and Product Name
139-96-8	205-388-7	2-[bis(2-hydroxyethyl)amino] ethanol; dodecyl hydrogen sulfate	Alkylsulfate	Stamex SVM Moussol-FF® 3/6 Kempartner AB: Unifoam S Kempartner AB: Unifoam OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF vs FOCUM: Silvara 1 (1%) vs FOCUM: Silvara APC 1 vs FOCUM: Silvara APC 3x3 vs FOCUM: Silvara ZFK (0.5%)
142-31-4	205-535-5	Sodium octyl sulphate	Alkylsulfate	Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) ; Syndura (6% fluorine free foam) Chemguard: 3% AFFF Foam Concentrate (C303) Chemguard: 3% Low Temp AFFF (C3LT) Dafo Brand AB: AFFF 3-6 % Fire Services Plus: FireAde Fire Services Plus: FireAde AR AFFF OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF OneSeven of Germany GmbH: OneSeven ® Foam Concentrate Class B-AFFF-AR Solberg : Solberg Patent US20080196908 TRAINING FOAM-N 1% F-0 #9141 vs FOCUM: Silvara ZFK (0.5%)

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CAS	EC	Substance name	Chemical group	Supplier and Product Name
142-87-0	205-568-5	Sodium decyl sulfate	Alkylsulfate	Chemguard: 3% AFFF Foam Concentrate (C303) Chemguard: 3% Low Temp AFFF (C3LT) Chemguard: 6% AFFF Foam Concentrate (C603) Chemguard: 6% Low Temp AFFF (C6LT) Dafo Brand AB: AFFF 3-6 % Dafo Fomtec AB: LS xMax Dafo Fomtec AB: MB -20 Solberg : Solberg Patent US20080196908 [REDACTED] TRAINING FOAM-N 1% F-0 #9141 vs FOCUM: Silvara 1 (1%) Solberg : Solberg Patent US20080196908
143-00-0	205-577-4	Dodecyl hydrogen sulfate;2-(2-hydroxyethylamino)ethanol	Alkylsulfate	Solberg: US20080196908
151-21-3	205-788-1	Sodium dodecyl sulphate	Alkylsulfate	Fire Services Plus: FireAde; FireAde AR AFFF
2235-54-3	218-793-9	Ammonium alkyl ether sulphate	Alkylsulfate	Kempartner AB: Unifoam, Unifoam S
25882-44-4	247-310-4	disodium;4-[2-(dodecanoylamino)ethoxy]-4-oxo-3-sulfonatobutanoate	Alkylsulfate	Angus Fire (Angus International: Angus Fire, National Foam and Eau et Feu.) : Expandol (aka Expandol 1-3), Expandol LT (aka Expandol 1-3LT)
273-257-1	68955-19-1	Sulfuric acid, mono-C12-18-alkyl esters, sodium salts	Alkylsulfate	N/A (identified via ECHA's dissemination website)
287-809-4	85586-07-8	Sulfuric acid, mono-C12-14-alkyl esters, sodium salts	Alkylsulfate	N/A (identified via ECHA's dissemination website)

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CAS	EC	Substance name	Chemical group	Supplier and Product Name
3088-31-1	221-416-0	Sodium 2-(2-dodecyloxyethoxy)ethyl sulphate	Alkylsulfate	Buckeye Fire Equipment Company: Buckeye High Expansion Foam (BFC-HX) (aka Hi-Ex 2.2)
577-11-7	209-406-4	1,4-bis(2-ethylhexoxy)-1,4-dioxobutane	Alkylsulfate	STHAMEX® K 1% F-15 #9143
68081-96-9	268-364-5	Sulfuric acid, mono-C10-16-alkyl esters, ammonium salts	Alkylsulfate	Orchidee Fire: Orchidex BlueFoam 3x3 Verde Environmental Inc (Micro Blaze): Micro-Blaze Out
68439-57-6	931-534-0, 270-407-8	Sulfonic acids, C14-16-alkane hydroxy and C14-16-alkene, sodium salts	Alkylsulfate	Dafo Fomtec AB: Enviro 3x3 Plus, Enviro 3x6 Plus, Environ 6x6 Plus STHAMEX® 3% F6 Multi-purpose detergent foam, STHAMEX® K 1% F-15 #9143 vaPUREx LV 1% F-10 #7141
68877-55-4	272-563-2	Sodium 3-[2-(2-heptyl-4,5-dihydro-1H-imidazol-1-yl)ethoxy] propionate	Alkylsulfate	OneSeven of Germany GmbH: OneSeven® Foam Concentrate Class B-AFFF, OneSeven® Foam Concentrate Class B-AFFF-AR
68877-55-4	272-563-2	Sodium 3-[2-(2-heptyl-4,5-dihydro-1H-imidazol-1-yl)ethoxy] propionate	Alkylsulfate	OneSeven of Germany GmbH: OneSeven® Foam Concentrate Class B-AFFF, OneSeven® Foam Concentrate Class B-AFFF-AR
68891-38-3	500-234-8	Sodium laureth sulfate	Alkylsulfate	Angus Fire: Expandol (aka Expandol 1-3), Expandol LT (aka Expanol 1-3LT), Respondol ATF 3-6% Dafo Fomtec AB: Enviro 3% ICAO, Enviro USP, LS xMax, Trainer E-lite
85338-42-7	286-718-7, 939-332-4	Sulfuric acid, mono-C8-10 (even numbered)-alkyl esters, sodium salts	Alkylsulfate	Angus Fire: Respondol ATF 3-6% Dafo Fomtec AB: Enviro 3x3 Ultra, LS aMax

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CAS	EC	Substance name	Chemical group	Supplier and Product Name
85665-45-8	939-262-4	Sulfuric acid, mono-C8-14 (even numbered)-alkyl esters, compds. with triethanolamine	Alkylsulfate	MOUSSOL®-FF 3/6 F-15 #7941, MOUSSOL®-FF 3/6 F-5 #7942, STHAMEX® 2% F6 Multi-purpose detergent foam, STHAMEX-SV/HT 1% F-5 #9142, TRAINING FOAM-N 1% F-0 #9141
90583-18-9	939-265-0, 292-216-9	Sulfuric acid, C12-14 (even numbered)-alkyl-esters, compds. with triethanolamine	Alkylsulfate	Dafo Fomtec AB: Enviro 3% ICAO, Enviro USP OneSeven of Germany GmbH: OneSeven Foam Concentrate Class A vs FOCUM: Silvara APC 3x6 Unifoam B o Yellow
90583-25-8	292-224-2	Sulfuric acid, mono-C6-12-alkyl esters, sodium salts	Alkylsulfate	
N/a	919-131-8	Fatty alcohol polyglycol ether sulfate, sodium salt	Alkylsulfate	BASF: Emulphor® FAS 30
N/a	944-611-9	Reaction mass of C-isodecyl and C-oundecyl sulphonatosuccinate	Alkylsulfate	Respondol ATF 3-6%
4292-10-8	224-292-6	(carboxymethyl)dimethyl-3-[(1-oxododecyl)amino]propylammonium hydroxide	Detergent	vs FOCUM: Silvara 1 (1%), Silvara ZFK (0.5%)

Siloxanes

A limited number of siloxanes were identified in this task, this might be because the usage of this substance group is still in the phase of development. This is further explained in the following. Only one substance belonging to siloxanes could be identified by CAS number. This substance is a mixture of siloxanes and silicones (CAS 117272-76-1). It was found in products by Denko, namely: 1% AFFF; 3% AFFF; 6% AFFF; Alcohol AFFF 3% - 6% Single or Double Strength. Judging by the name, it could be that these substances were used in combination with fluorinated substances. However, for the sake of completeness the substance is named although it is not used as a PFAS-replacement. This information is shown in the table below, where also the chemical structure is shown.

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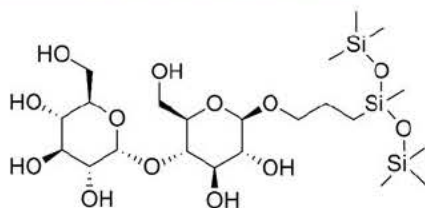
Table B.3 Siloxanes (identified by CAS) incl. CAS/EC identifier, the substance name, chemical group and the supplier and/or product name

CAS	EC	Substance name	Chemical group	Supplier & Product Name	Chemical structure
117272-76-1	601-468-4	Siloxanes and Silicones, 3-hydroxypropyl Me, ethers with polyethylene glycol mono-Me ether	Siloxanes	1% AFFF Denko 3% AFFF Denko 6% AFFF Denko Alcohol AFFF 3% - 6% Single or Double Strength Denko	

In addition, publications by Hetzer et al. presented various sugar-based siloxanes for which CAS-numbers are not available. For a better understanding, in Figure B.2 a sugar-based siloxane, as presented by Hetzer et al., is shown. It is important to note that these substances are used without further addition of PFAS substances. The most recent publication by these researchers states that siloxane-based firefighting foam concentrate shows an extinguishing performance which significantly surpasses the commercial PFAS-free foams (whereby the actual product is not named) and nearly meets the performance of the PFAS-containing AFFF in fire suppression tests based on the NATO standard fuel F-34 (class B fire). However, no commercial product containing these substances was identified in this task.

Regarding their persistency, some siloxanes are known SVHC, having identified PBT and/or vPvB properties (cyclic D4, D5, D6) and others (linear) are currently undergoing PBT-assessment (e.g. octamethyltrisiloxane). In this context, the publications highlight that the formation of the desired product and its purity were verified after the filtration process. No more information is available at this time.

Figure B.2 Sugar-based siloxane as described by Hetzer et al.



For more information on these substances please refer to the individual publications (Hetzer, R. et al. ; Hetzer, R. et al. 2014; Hetzer, R. H. und Kümmerlen 2016; Hetzer, R. H. et al. 2015).

Proteins

Regarding protein-based foams also only one substance with a CAS number could be identified. This belongs to silk-based protein hydrolysate (CAS 306-235-8). However, the associated product/foam manufacturer was not identified. Some SDS mention proteins from horn and hoof (National Foam) or hydrolysed protein (Gepro Group PROFOAM 806G). In these cases, no CAS number was given. The sources mentioning horn and hoof-based proteins also recommended that these should not be used because of the risk of epizootic diseases.

B.1.1.3. Substance identification - PFAS

Generally, most information on PFAS in fire-fighting foams was found in the scientific literature. This is partially due to the fact that SDS and supplier information only indicate general terms like "fluorinated surfactant" without naming a CAS number and/or referring to propriety information. Environmental agencies mostly also cite scientific literature, so this information overlaps with substances already identified in the review of scientific literature. This is also true for information from legislation (REACH, Stockholm, Basel Convention).

When searched in pubmed and google scholar, the following search terms were used:

("fluorochemical" OR "per- and polyfluoroalkyl" OR "perfluoroalkyl" OR "polyfluoroalkyl" OR "fluorinated" OR "PFAS") AND ("fire fighting" OR "airport" OR "fire")*

As of April 2019, this search yielded 86 hits. Those publications were mostly highly relevant, and the substance details were extracted into excel sheets relevant for the next working steps.

An additional source of information is case studies and monitoring activities. However, these are considered to be of less importance because mostly only a very limited variety of PFAS substances was covered. Additionally, when environmental/human samples are considered, for fluorinated foams, also environmental and biological degradation processes need to be considered. For example, it is known that perfluorosulfonamides, undergo abiotic degradation as well as in vivo and in vitro biotransformation (DanEPA 2015).

With regards to the substances identified in the scientific literature, for a large share it was not possible to find a CAS/EC number. Sixty-three substances were identified by CAS/EC number, while around 213 were only identified by substance name/structure. This lack of CAS numbers may be due to the fact that those substances have been described for the first time by the respective author or are perhaps polymeric substances that do not necessarily have CAS numbers. In general, these numbers might also indicate that a lot of substances have been used that are currently poorly known.

The following information relates only to those substances that were fully identified in terms of CAS/EC, substance name and/or acronym.

Based on the CAS-identified PFAS-substances that were/are used in AFFF the following grouping is possible, indicated in brackets is the number of CAS-identified substances:

- Unsubstituted long chain PFAS (14);
- Unsubstituted short chain PFAS (8);
- Substituted short and long chain PFAS (12);
- Fluorotelomers (22); and
- Others (7).

Long Chain PFAS

The group of **long chain PFAS** (defined by OECD as perfluorosulfonic acids (PFSAs) with $C \geq 6$ and perfluorocarboxylic acids (PFCAs) with $\geq C8$) encompasses the following substances:

PFSAs with $\geq C6$

- PFHxS (C6);
- PFHpS (C7);
- PFOS (C8);

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- PFNS (C9);
- PFDS (C10); and
- PFUnDS (C11).

As can be seen in the table below, the identified sulfonic acids exhibit chain length up to 11 perfluorinated carbons.

Table B.4 PFASs (identified by CAS) with $\geq C_6$ incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
355-46-4	206-587-1	Perfluorohexane sulfonic acid	PFHxS	Ansul AFFF Ansulite® 3M LightWater Angus Fire, na Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A™ 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988
375-92-8	206-800-8	perfluoroheptane sulfonic acid	PFHpS	3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988
1763-23-1	217-179-8	Perfluorooctanesulfonic acid	PFOS	3M AFFF ("PFASs have been components of 3M AFFF from the 1970s to 2001") 3M LightWater FC-203FC 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1988 3M 1989 Ansul Ansulite® AFFF Angus Fire, na Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A™ Hazard Control Technologies, Inc., 2003 F-500 [REDACTED] STHMEX-AFFF 3%
68259-12-1	N/a	Perfluoronone sulfonic acid	PFNS	3 M Lightwater PFASs have been components of 3M AFFF from the 1970s to 2001
335-77-3	206-401-9	Perfluorodecanesulfonic acid	PFDS	3M Ansul AFFF Angus Fire, N/a Formtec MB 5
749786-16-1	N/a	Perfluoroundecan sulfonic acid	PFUnDS	No product/supplier is mentioned; Publications are based on environmental samples

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The identified PFCAs encompass the following substances:

PFCAs with ≥C8:

- PFOA (C8);
- PFNA (C9);
- PFDA (C10);
- PFUnDA (C11);
- PFDODA (C12);
- PFTrDA (C13);
- PFTeDA (C14); and
- PFODA (C18).

The carboxylic acids exhibit chain length up to 18 perfluorinated carbons. All of the substances were identified in various “old” products (newest product is from 2007) from different manufacturers. This can be seen in the table below.

Table B.5 PFCAs (identified by CAS) with ≥C8 incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
335-67-1	206-397-9	Perfluorooctanoic acid	PFOA	Ansul AFFF Ansul te® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988 OneSeven B-AR ARC Miljö Towalex plus Towalex 3x3 Towalex 3% super Towalex 3% master Sthamex AFFF-P 3% FC-203FC Light Water 3M
375-95-1	206-801-3	Perfluorononanoic acid	PFNA	Ansul AFFF Ansul te® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan OneSeven B-AR ARC Miljö Towalex 3x3 Towalex 3% master Hazard Control Technologies, Inc., 2003 F-500

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CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
335-76-2	206-400-3	Perfluorodecanoic acid	PFDA	Ansul AFFF Ansulite® 3M LightWater 3M FC-203FC Light Water Fomtex Arc 3x3 Towalex plus Towalex 3x3 Towalex 3% master
2058-94-8	218-165-4	Perfluoroundecanoic acid	PFUnDA	3M LightWater 3M LightWater FC-203FC Ansul Ansulite® ANSUL Ansulite 6 % AFFF (Formula 1559-22 ICAO-B)
307-55-1	206-203-2	Perfluorododecanoic acid	PFDoDA	Ansul AFFF Ansulite® 3M LightWater Sthamex F-15 Towalex 3% master
72629-94-8	276-745-2	Perfluorotridecanoic acid	PFTriDA	PFCAs were primary components in early 3M AFFFs from 1965 up to 1986
376-06-7	N/a	Perfluorotetradecanoic acid	PFTeDA	3M AFFFs from 1965 up to 1987 Ansul AFFF FC-203FC Light Water 3M
16517-11-6	240-582-5	Perfluorostearic acid	PFODA	No product/supplier is mentioned; Publications are based on environmental samples

Short chain PFAS

Short chain PFAS were also identified in this study, namely:

PFASs with C<6:

- PFETs (C2);
- PFPrS (C3);
- PFBS (C4); and
- PFPeS (C5).

The list below shows that the identified sulfonic acids cover chain lengths from C2-C5.

Table B.6 PFASs (identified by CAS) with <C6 incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
354-88-1	N/a	Perfluoroethane sulfonic acid	PFETs	3M AFFFs Shorter chains C2-C3 PFASs used in from 1988 to 2001
423-41-6	N/a	Perfluoropropane sulfonic acid	PFPrS	3M AFFFs Shorter chains C2-C3 PFASs used in from 1988 to 2001
375-73-5	206-793-1	Perfluorobutanesulfonic acid	PFBS	Ansul AFFF Ansulite® 3M LightWater Anqus Fire, N/a

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				Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A ™ 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988
2706-91-4	220-301-2	Perfluoropentane sulfonic acid	PFPeS	No product/supplier is mentioned; Publications are based on environmental samples

Also carboxylic acids have been identified. Contrary to the sulfonic acids, the carboxylic acids were only found starting from C4.

PFCAs with < C8:

- PFBA (C4);
- PFPeA (C5);
- PFHxA (C6); and
- PFHpA (C7).

In the table below, the short chain PFCAs are shown.

Table B.7 PFCAs (identified by CAS) with <C8 incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
375-22-4	206-786-3	perfluoro-n-butanoic acid	PFBA	Ansul AFFF Ansul te® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A ™ 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF OneSeven B-AR ARC Miljö Towalex 3x3 Towalex 3% master Sthamex AFFF-P 3%
2706-90-3	220-300-7	Perfluoropentanoic acid	PFPeA	3M LightWater FC-203FC 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988 Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Ansul AFFF Ansul te®

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CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
307-24-4	206-196-6	Perfluorohexanoic acid	PFHxA	Ansul AFFF Ansul te® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF 3M 1999 3M 1992 3M 1993 3M 1998 (slightly different shares) 3M 1989 3M 1988 OneSeven B-AR ARC Miljö Towalex plus Towalex 3x3 Towalex 3% super Towalex 3% master Sthamex AFFF-P 3%
375-85-9	206-798-9	Perfluoroheptanoic acid	PFHpA	Ansul AFFF Ansul te® 3M LightWater Angus Fire, N/a Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2007; Hi Combat A™ Angus Fire, 2004 Tr dol S 3 % 3M, 2005; ATC-603 Light water ATC3 3M, 1999; FC-203FC Light water Brand AFFF FC-203FC Light Water 3M OneSeven B-AR ARC Miljö Towalex 3x3 Towalex 3% master Sthamex AFFF-P 3%

In general, both short and long chain PFAS were identified as substances used in AFFF. One author highlights that PFCAs were primary components in early 3M AFFFs from 1965 up to 1986 (Barzen-Hanson und Field 2015).

Derivates of perfluoroalkyl sulfonic PFAS (also PASF-based substances)

All the named substances above are characterized by a perfluorinated alkaline carbon chain that is connected to a sulfonic- or carboxylic acid head group. In other PFAS substances, this head group is also equipped with additional chemical groups. This group is also called perfluoroalkane sulfonyl fluoride substances (PASF), as their synthesis is based on perfluoroalkane sulfonyl fluoride.

This can be for example an amide (sometimes methylated or ethylated). However, in most cases, these substances were not found when the actual foam was tested but rather when environmental samples were tested. In addition, some of the substances are also known to be environmental transformation products. Other substances are raw materials for surfactant and surface protection products (EtFOSE and N-MeFOSE) (Buck et al. 2011). In this sub group, the following substances were found:

- PFOSaAm;
- C7-FASA (PFHpSA);
- C8-PFSiA (PFOSI);

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- EtFOSAA;
- EtFOSE;
- FBSA;
- FOSA;
- FOSAA;
- FOSE;
- N-MeFOSA;
- N-MeFOSE;
- PFBSaAm;
- N-[3-(Dimethyloxidoamino)propyl] -3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluor-1-octanesulfonamid; and
- (Carboxymethyl)dimethyl [3- (gamma-omega-perfluor-1-C6-14-Alkansulfonamid)propyl]ammonium.

In addition, some of those compounds are known PFOS-precursors (for example PFOSaAm, EtFOSAA, PFOSI, EtFOSE).

Table B.8 Identified derivatives of perfluoroalkyl sulfonic PFAS (also PASF-based substances)

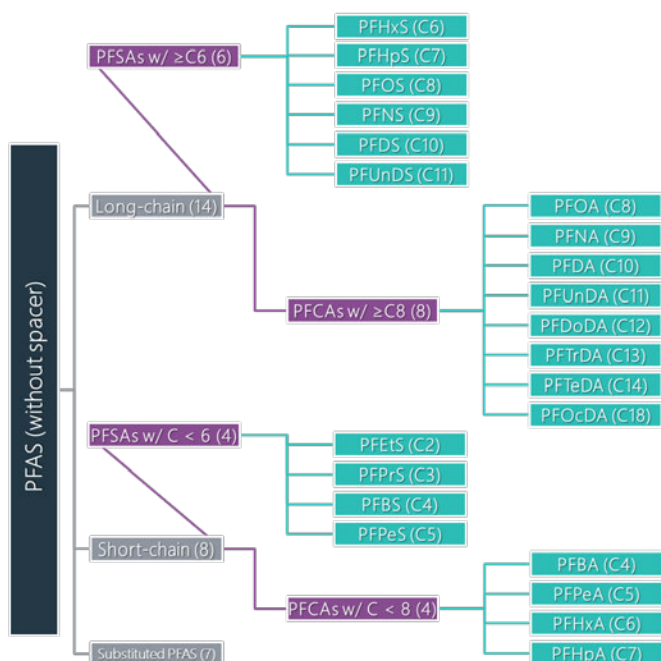
CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
13417-01-1	236-513-3	PPerfluoroalkyl sulfonam do amines	PFOSaAm	National Foam ; Ansulite; 3M lightwater; 3M
167398-54-1	N/a	Perfluoroheptane sulfonam doethanol	C7-FASA (PFHpSA)	3 M Lightwater was used from 1988 until 2001 OR Ansul (telomer-based foam)
647-29-0	N/a	N/a	C8-PFSiA (PFOSI)	3M 1988 3M 1989
2991-50-6 / 1336-61-4	221-061-1	N-Ethyl perfluorooctane sulfonam doacetic acid	EtFOSAA	No product/supplier is mentioned; Publications are based on environmental samples
4151-50-2	223-980-3	N-Methyl perfluorooctane sulfonam doacetic acid	EtFOSE	No product/supplier is mentioned; Publications are based on environmental samples
68298-12-4	N/a	N-Methylperfluorobutanesulfonam de	FBSA	No product/supplier is mentioned

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CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
2806-24-8	N/a	perfluorooctane sulfonamido acetic acid	FOSAA	No product/supplier is mentioned; Publications are based on environmental samples
754-91-6	212-046-0	Perfluorooctane sulfonamido	FOSA	No product/supplier is mentioned; Publications are based on environmental samples
10116-92-4	N/a	N/a	FOSE	No product/supplier is mentioned; Publications are based on environmental samples
2355-31-9	N/a	N-methyl perfluorooctanesulfonamidoacetic acid	N-MeFOSA	No product/supplier is mentioned; Publications are based on environmental samples
24448-09-7	246-262-1	N-Methyl perfluorooctane sulfonamidoethanol	N-MeFOSE	No product/supplier is mentioned; Publications are based on environmental samples
68555-77-1	271-455-2	perfluoroalkyl sulfonamido amines	PFBSaAm	No product/supplier is mentioned; Publications are based on environmental samples
80475-32-7	279-481-6	N-[3-(Dimethyloxidoamino)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-Tridecafluor-1-octanesulfonamid	N/a	Dupont, Forafac® 1183
133875-90-8	N/a	(Carboxymethyl)dimethyl [3-(gamma-omega-perfluor-1-C6-14-Alkylsulfonamid)propyl]ammonium (inneres Salz)	N/a	Dupont, Forafac® 1203

In addition to the tables above, the identified substances and their respective chemical relationship can be visualised in terms of a hierarchical clustering. This is shown in the figure below.

Figure B.3 Hierarchical clustering of the identified short-, long-chain and substituted PFAS substances



Fluorotelomers

Fluorotelomers are defined by having an additional non-fluorinated spacer between the perfluorinated alkyl chain and the charged head group (denoted as number of perfluorinated carbons: number of non-fluorinated carbons). The fully identified substances (i.e. by CAS/EC number) are shown in Table B.9.

As shown in the table below, the 22 identified fluorotelomers cover a wide range of positively/negatively charged head groups or combinations of those. Most of the fully identified substances, exhibit the xx:2 structure, where two non-fluorinated carbon atoms are inserted between the perfluorinated carbon chain and the head group. However, in the case of fluorotelomer betaines also xx:1:2 and xx:3 are found. In the latter case, three non-fluorinated carbon atoms are inserted between the perfluorinated carbon chain and the head group. In the case of the xx:1:2 substances, an additional fluorinated carbon is inserted between the perfluorinated alkyl chain and the non-fluorinated spacer.

Based on the manufacturing dates that are cited in the respective publications, it can be assumed that the use of fluorotelomers in fire-fighting foams began later than the use of traditional PFAS substances without a non-fluorinated spacer.

The following head groups have been identified:

- Alkylbetaine (AB);
- Betaine (B);

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- Carboxylic acid (CA);
- Hydroxy (OH);
- Thioamido sulfonates (TAoS);
- Unsaturated carboxylic acid (UCA);
- Sulfonamido betaines (SaB);
- Sulfonamide amine (SaAm); and
- Thio hydroxy ammonium (THN+).

Table B.9 Fluorotelomer (identified by CAS) substances incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
34455-35-1	N/a	10:2 Fluorotelomer sulfonam de alkylbetaine	10:2 FTAB	F-500, Hazard Control Tech., 1997 National Foam 2005 National Foam 2007 National Foam 2008 Fire Service Plus AFFF 2011 National Foam 2003-2008
53826-13-4	N/a	10:2 Fluorotelomer carboxylic acid	10:2 FTCA	No product/supplier is mentioned; Publications are based on environmental samples
70887-84-2	N/a	10:2 fluorotelomer unsaturated carboxylic acid	10:2 FTUCA	No product/supplier is mentioned; Publications are based on environmental samples
278598-45-1	N/a	Fluorotelomer sulfonam do betaines	12:2 FtSaB	3M Ansul, 2006 Ansul Anulite ARC
757124-72-4	816-391-3	Fluorotelomer sulfonates	4:2 FTS	Angus Fire, 2004 Tridol S 3% Ansul 2002 Anslite 3% AFFF-DC-6 Hazard Control Tech 1197 F-500 National Foam

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CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
1432486-88-8	N/a	4:2 fluorotelomer th oam do sulfonates	4:2 FTAoS	Ansul AFFF formulations Angus Fire, 2004 Tridol S Ansul, 2002 Ansulite 3% AFFF DC-3 Ansul, 2006 Ansul Anulite ARC Hazard Control Tech., 1997 F-500 Chemguard Ansul Angus
171184-02-4	N/a	5:1:2 fluorotelomer betaine	5:1:2 FTB	3M Ansul, 2002 Ansulite 3% AFFF DC-3 Buckeye 2009 Buckeye AFFF 2004
171184-14-8	N/a	5:3 fluorotelomer betaine	5:3 FTB	3M Buckeye
34455-29-3	252-046-8	6:2 Fluorotelomer sulfonam de betaine	6:2 FTAB	Chemours, STHAMEX® -AFFF 3% F-15 #4341 Dupont Forafac 1157 3M National Foam F-500, Hazard Control Tech., 1997 (Foam 1) Angus Fire, 2004 Tridol S Angus Fire, 2000 Niagara 1-3 Chemours
647-42-7	211-477-1	6:2 Fluorotelomer alcohol	6:2 FTOH	No product/supplier is mentioned; Publ cations are based on environmental samples

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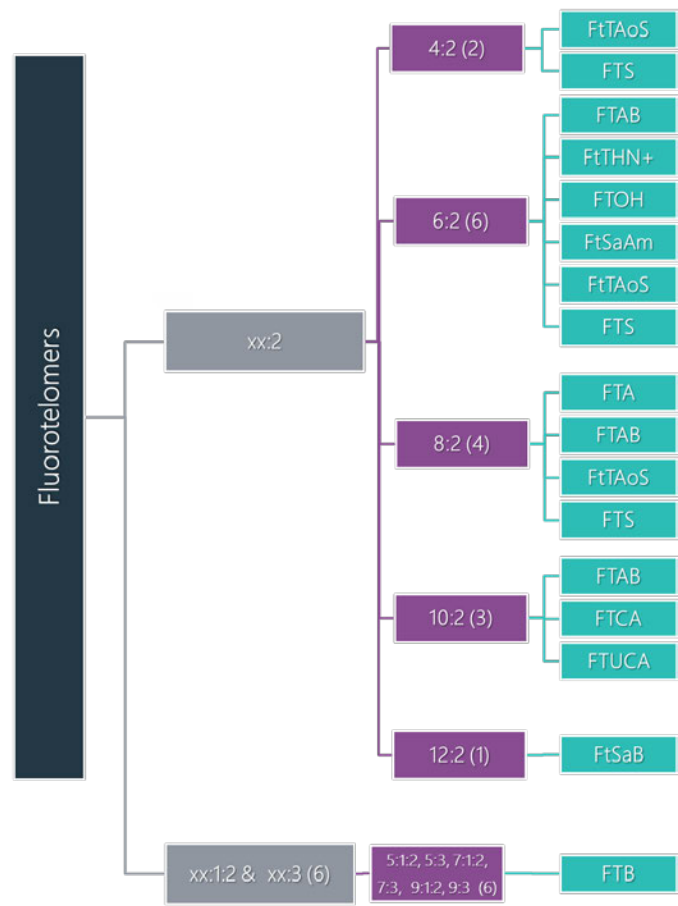
CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
27619-97-2	248-580-6	6:2 Fluorotelomer S ulfonate	6:2 FTS	GmbH & Co. KG STHMEX-AFFF 3% Hazard Control Tech., 1997 F-500 Angus Fire, 2004 Tridol S 3 % Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan Angus Fire, 2004 Tridol S 3 % Ansul, 2002 Ansulite 3 % AFFF - DC-4 Ansul, 2006; Ansul Anulite ARC National Foam 2005 National Foam 2007 National Foam 2008 (slightly different shares)
1383438-86-5	N/a	6:2 fluorotelomer sulfonam de amine	6:2 FtSaAm	3M, National Foam 2005 National Foam 2007 National Foam 2008 (slightly different shares)
88992-47-6	N/a	6:2 fluorotelomer th oether am do sulfonic acid	6:2 FtTAoS	Angus Fire, 2004 Tridol S Ansul 1986 Ansul 1987 Angus Fire, 2000 Niagara 1-3 Ansul, 2002 Ansulite 3% AFFF DC-3 Ansul 2009 Ansul 2010 Chemguard 2008 F-500, Hazard Control Tech., 1997
88992-46-5	N/a	6:2 fluorotelomer th o hydroxy ammonium	6:2 FtTHN+	3M
171184-03-5	N/a	7:1:2 fluorotelomer betaine	7:1:2 FTB	3M Buckeye 2009
171184-15-9	N/a	7:3 fluorotelomer betaine	7:3 FTB	Buckeye Ansul, 2002 Ansulite 3% AFFF DC-3
27854-31-5	N/a	8:2 Fluorotelomer carboxylic acid	8:2 FTCA	F-500, Hazard Control Tech., 1997

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CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
34455-21-5	N/a	8:2 Fluorotelomer sulfonate de betaine	8:2 FTAB	National Foam, F-500, Hazard Control Tech., 1997 National Foam 2005 National Foam 2007 National Foam 2008 (slightly different shares) Fireade
39108-34-4	254-295-8	Fluorotelomer sulfonates	8:2 FTS	Ansul, 2002 Anslite 3 % AFFF - DC-5 Hazard Control Tech., 1997 F-500 Angus Fire, 2000 ; Niagara 1-3, Angus Fire, 1997; Forexpan National Foam 2005 National Foam 2007 National Foam 2008
1383439-45-9	N/a	8:2 fluorotelomer th oam do sulfonates	8:2 FTAoS	Chemguard, Ansul, 2006; Ansul Anulite ARC; Ansul, 2002 Anslite 3% AFFF DC-3 Angus Fire, 2004 Tridol S Angus Fire, 2000; Niagara 1-3 Hazard Control Tech., 1997 F-500;
171184-04-6	N/a	9:1:2 fluorotelomer betaine	9:1:2 FTB	3M Buckeye AFFF 2004 Buckeye 2009
171184-16-0	N/a	9:3 fluorotelomer betaine	9:3 FTB	Buckeye 2009 3M 1988 3M 1989 3M 1993A 3M 1993B 3M 1998 3M 2001 Ansul, 2002 Anslite 3% AFFF DC-3

In addition to this table, a hierarchical clustering was elaborated. This is shown in the figure below.

Figure B.4 Hierarchical clustering of identified fluorotelomers



Other PFAS substances

In some cases, perfluorinated substances that do not belong to any of the named groups (long-/short-chain PFAS, fluorotelomers, and derivatives of PFAS) were identified (**Others**). These substances are shown in the table below. Also shown below is the substance Dodecafluoro-2-methylpentan-3-one, a fluorinated ketone.

Figure B.5 Chemical structure of Dodecafluoro-2-methylpentan-3-one, a fluorinated ketone

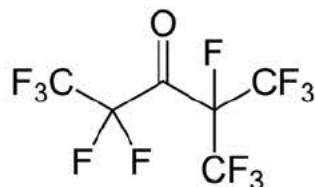


Table B.10 Other per- or polyfluorinated substances (identified by CAS) incl. CAS/EC identifier, the designation, the acronym and the supplier and/or product name

CAS	EC	Designation (synonyms)	Acronym	Supplier and Product Name
1280222-90-3	480-310-4	ammonium 2,2,3-trifluor-3-(1,1,2,2,3,3-hexafluoro-3-trifluoromethoxypropoxy), propionate	ADONA	Mentioned in annex_xv_svhc_ec_206-397-9 pfoa 11549 as a subst tute. However, no other source for this information.
756-13-8	616-243-6 / 436-710-5	Dodecafluoro-2-methylpentan-3-one	N/a	3M NOVEC TM 1230
161278-39-3	500-631-6	Poly(1,1,2,2-tetrafluoro-1,2-ethanediyl), α-fluoro-ω-2-[3-((carboxylatomethyl)dimethylammon o)propylaminosulfonyl]ethyl-	N/a	PROFOAM Profilm AFFF
70969-47-0	N/a	Thiols, C8-20, gamma-omega-perfluoro, telomers with acrylamide	Thiols, C8-20, gamma-omega-perfluoro, telomers with acrylamide	Towalex 3% master
70829-87-7	N/a	Sodium p-perfluorooctenonylbenzene sulfonate	OBS	No product/supplier is mentioned; Publications are based on environmental samples
13269-86-8	236-267-7	Bis(trifluorovinyl)ether	N/a	Fire-extinguishing foam cited in Nordic working paper

Conclusions from the substance identification

In this substance identification process, three substance classes, that are/were used in firefighting foams, were considered: fluorine-free replacements, PFAS substances, and fluorinated but not-PFAS alternatives. The main outcomes of this task are as follows:

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- For the latter substance class (fluorinated but not-PFAS alternatives) no substances were found, as also confirmed by experts;
- In the case of PFAS substances, various carboxylic/sulfonic short- and long chain PFAS were found. Additionally, also a variety of fluorotelomers. These substances differ in chain length and substitution and only a relatively small amount of these substances could be identified by CAS/EC number. Furthermore, other PFAS substances were found, that do not belong to any of the named PFAS-categories; and
- The identified fluorine-free PFAS-replacements can be grouped into four classes: hydrocarbons, detergents, siloxanes and proteins. For the latter two classes, the gathered information and the amount of identified substances are relatively small. In the case of the siloxanes, the usage of these substances in firefighting foams is still under development. In contrast to this, a variety of hydrocarbons (around 24) and detergents (33) were identified, that are used as a replacement for PFAS-substances.

In summary, a large number of highly diverse PFAS substances were found in the context of use in fire-fighting foams. This could be an indication of extensive replacement chemistry that was initiated due to industry and regulatory concerns about the potential health and environmental impacts of long-chain PFAS and lately also short-chain PFAS.

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B.1.2. Composition of the substance(s)

For each constituent/ impurity/ additive (particularly for those which influence the outcome of the dossier) the following information is provided:

- Chemical Name
- EC Number
- CAS Number
- IUPAC Name
- Molecular Formula
- Structural Formula
- Molecular Weight
- Typical proportion %
- Real proportion (range) in %

Chemical name, EC and CAS numbers are provided in the previous section. However, the other pieces of information have not been collected for the present study (with the exception of some example molecular structures provided in the previous section). This reflects that a large number of relevant substances has been identified and that the information is not considered to affect the outcome of the dossier, which proposes a restriction not of the individual substances but rather for the use of PFAS in fire-fighting foams as a group based on the definition provided in Section 1.1.1.7.

B.1.3. Physicochemical properties

Physicochemical properties of the substances have not been reviewed in detail here, for the same reasons as highlighted under 'composition' above. This may need to be considered further when any full Annex XV dossier is drawn up.

B.1.4. Justification for grouping

See Section 1.1.2.

B.2. Manufacture and uses (summary)

The table below summarises some of the key results that have been discussed in more detail above (Annex A).

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Table B.11 Summary of key preliminary market analysis results

	PFAS-based fire-fighting foams	Fluorine-free alternatives
Tonnage of foam used [1]	14,000-20,000 tonnes per year	7,000-9,000 tonnes per year
Tonnage by substance / Substances most commonly used	480-560 tonnes of fluoro-surfactants used annually in EU. Breakdown of tonnage for 8 substances available (see Table A.1 in Annex A and directly below the table), but for majority of tonnage the substances are not known.	No quantitative data. Main alternatives used are based on hydrocarbon surfactants and detergents. Specific products are discussed in Annex E.2 (analysis of alternatives).
Breakdown of tonnage by use sector	Chemical/Petrochemical: 59% Municipal fire brigades: 13% Marine applications: 11% Airports: 9% Military: 6% Ready for use products: 1%	Chemical/Petrochemical: 29% Municipal fire brigades: 44% Marine applications: 16% Airports: 7% Military: 2% Ready for use products: 1%
Prices	Average (uncertain): €3 Reported range: €2 to €30 per litre	Average (uncertain): €3 Reported range: €0.7 to €10 per litre
Revenues [2]	Best estimate: €60 million Potential range: €28-600 million	Best estimate: €27 million Potential range: €5-90 million
Functions provided and types of fires used for	Surfactant to form a film over the burning surface. Particularly relevant for fire involving flammable liquids (Class B fires). Consultation suggests it is used both in training and true emergency responses.	Those fluorine-free foams considered alternatives to PFAS-based foams in principle provide the same (or a similar) function. Consultation suggests it is used both in training and true emergency responses, but in some cases in training only.
Trends	Rapid shift from PFAS towards fluorine-free foam in recent years, expected to continue.	

Notes: [1] The original data from Eurofeu covers approximately 70% of the market, therefore this has been inflated to reflect the whole market. The lower end of the range represents the original data, whilst the upper end represents the extrapolation to the whole market.

[2] The best estimate is based on the upper end of the quantity range and a weighted average price of €3/litre. The potential range is based on the lower end of the quantity range multiplied with the lower end of the price range, and the upper end of the quantity range multiplied with the upper end of the price range. An average density of 1 kg/litre has been assumed.

B.3. Classification and labelling

To avoid duplication with the ongoing work of the PFAS working group, a review of the classification and labelling has not been undertaken.

B.4. Environmental fate properties

B.4.1. Mobility and persistence

PFAS is a term used to cover approximately 4,700 specific chemical species¹⁰¹. Longer chain ($\geq$ C8) PFAS compounds have been used within industry as surfactants specifically because of their potent water and oil repellence at low concentrations (Buck, 2011). Prior to 2000 the use of PFAS within fire-fighting foams in Europe utilised the salts of C8 PFAS compounds such as PFOS and PFOA, particularly the ammonium salt of PFOA (APFO) (CAS 3825-26-1)¹⁰².

As of the late 1990s growing concerns around longer chain PFAS compounds highlighted that they were highly mobile in the aquatic and terrestrial environment, highly persistent, and had the capability to bioaccumulate up food chains¹⁰³. Many longer chain PFAS species also had toxic effects identified. The ECHA SVHC nomination dossier for PFOA (2013) indicated that PFOA (from the ammonium salt) is readily absorbed by the body and can pass to the foetus (by blood) and child (by mother's milk), and concentrates in the blood, liver and kidneys with toxic effects. The nomination also notes that the RAC identified sufficient scientific evidence to conclude that PFOA could also be a reproductive toxin for the unborn child.

Concerns over the mobility and persistence of longer chain PFAS substances, along with potential health effects led to an industry initiative in the early to mid-2000s to switch to shorter chain ($\leq$ C6) PFAS alternatives (UNECE, 2004). For fire-fighting foams this includes the salts of C6 or lower based PFAS substances¹⁰⁴. However, concerns have continued that shorter chain PFAS substance are also mobile (if not more mobile) than $\geq$ C8 substances and are highly persistent albeit with potentially lower bioaccumulation¹⁰⁵.

The table below provides as an example of the mobility of PFAS compounds with different carbon chain lengths (based on log K_{oc}) as an indicator that shorter chain PFAS are likely to be highly mobile. Kjoltholt (2015)¹⁰⁶ indicates that WWTPs are likely to be ineffective against short-chain PFAS, just as they are also ineffective against longer chain PFAS compounds.

Table B.1 Overview of PFAS substances mobility using log K_{oc}

Carbon chain length	Species	CAS number	Log K _{oc}
PFCA's			
11	Perfluoroundecanoate (PFUnDA)	2058-94-8	3.3 to 3.56
10	Perfluorodecanoate (PFDA)	335-76-2 // 3830-45-3 // 3108-42-7	2.76 to 2.96

¹⁰¹ OECD, 2018, PFAS database, toward a new comprehensive global database of per and polyfluoroalkyl substances.

¹⁰² Stockholm Convention risk management evaluation dossier for PFOA, its salts and related compounds UNEP/POPs/POPRC.14/6/Add.2

¹⁰³ UNECE, 2004, PFOS dossier for purpose of nominating PFOS to the LRTAP Protocol and Stockholm Convention.

¹⁰⁴ Tyco fire protection, 2016, 'Transition if the firefighting foam industry from C8 to C6 fluorochemistry'.

¹⁰⁵ Cousins et al, 2018, 'short-chain perfluoroalkyl acids: environmental concerns and regulatory strategy under REACH', Environmental science Europe vol 30.

¹⁰⁶ Kjoltholt et al, 2015, 'short chain polyfluoroalkyl substances (PFAS) a literature review of information on human health effects and environmental fate and effect of short chain PFAS', Danish Ministry for Environment.

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9	Perfluorononanoate (PFNA)	375-95-1	2.36 to 3.69
8	Perfluorooctanoate(PFOA)	335-67-1	1.89 to 2.63
8	Perfluorooctane sulfonate (PFOS)	1763-23-1	2.4 to 3.7
6	Perfluoroheptane sulfonate (PFHxS)	355-46-4	2.4 to 3.1
6.1	Perfluorohexanoate (PFHxA)	307-24-4	1.3
4	Perfluorobutane sulfonate (PFBS)	375-73-5 // 59933-66-3	1.2 to 1.79
4	Perfluorobutanoate (PFBA)	375-22-4	1.9
Fluorotelomers			
8	8:2 Fluorotelomer alcohol (8:2 FTOH)	678-39-7	4.13
6	6:2 Fluorotelomer alcohol (6:2 FTOH)	647-42-7	2.43
4	4:2 Fluorotelomer alcohol (4:2 FTOH)	2043-47-2	0.93

*reference ITRCP PFAS factsheet. <https://pfas-1.trcweb.org/>

B.4.1. Degradation

This has not been assessed in detail in this study, beyond the discussion of persistence above.

B.4.2. Environmental distribution

This has not been assessed in detail in this study.

B.4.3. Bioaccumulation

This has not been assessed in detail in this study.

B.4.4. Secondary poisoning

See Section B.9.6.

B.5. Human health hazard assessment

High level comments on the hazards associated with PFAS substances are provided in Section 1.1.4. However, in order to assess the potential human health and environmental impacts of a potential restriction, the hazards of fluorine free alternatives to PFAS-based fire-fighting foams were assessed in more detail.

Review of hazards of fluorine-free alternatives

In this sub chapter the hazards of the identified fluorine-free alternative substances have been assessed based on their PNEC (Predicted No Effect Concentration). As highlighted in ECHA's guidance document on information requirements and chemical safety assessment (Chapter

R.10: Characterisation of dose [concentration]-response for environment)¹⁰⁷, the PNEC represents “the concentration of the substance below which adverse effects in the environmental sphere of concern are not expected to occur”.

Mostly, PNEC values are derived from acute and chronic toxicity single-species or multi-species data. To extrapolate from this data, an empirical assessment factor is necessary to make assumptions for the entire ecosystem. In combination with predicted environmental concentration (PEC) values PNECs are used to calculate a risk characterisation ratio. For this the PEC is divided by the PNEC, thus if the PNEC exceeds the PEC, it can be concluded that there is no environmental risk based on the concentration of the observed substance. However, in this project, the sole consideration of a PNEC value is not advisable, based on the uniqueness of PFAS substances. In an ecotoxicological assessment, this uniqueness is for example expressed by the fact that they are not biodegradable. ECHA’s guidance document highlights that the “degradation of organic substances in the environment influences exposure and, hence, it is a key parameter for estimating the risk of long-term adverse effects on biota”¹⁰⁸. Thus, in the following not only PNECs but also data on biodegradation and bioaccumulation is considered.

It should be noted that the following considerations are not meant as a full risk assessment; they are meant rather as an indicative comparison of the identified substances among each other and against the fluorinated substances.

Based on their REACH registration dossiers it was possible to identify most of the PNECs, biodegradation and bioaccumulation data of the fluorine-free alternative substances and the selected fluorinated substances. In the following table an overview of the substances, their respective products, CAS numbers, PNECs, bioconcentration factors (BCFs), and biodegradation assessments are given. Due to the focus of this project the PNECs for freshwater and soil were considered.

Table B.1 Overview on substances used in fluorine-free fire-fighting foams and one substance used in a fluorinated foam. Shown are the product, CAS/EC, PNECs, and the used reference. The respective lowest PNECs are highlighted in bold.

Substance	Product	CAS	PNEC aqua (freshwater) mg/L	PNEC soil (mg/kg soil dw)	Bio- degradation (... biodegradable in water)	Bio- accumul- ation (BCF)	Reference
1-dodecanol	Respondol ATF 3/6	112-53-8	0.001	0.132	Readily	750	ECHA RD
1-tetradecanol	Respondol ATF 3/6	112-72-1	0.0063	0.428	Readily	1000*	ECHA RD
Sodium laureth sulphate	Respondol ATF 3/6	68891- 38-3	0.24	0.0917	Readily	waived	ECHA RD
Alkylamidobetaine	Moussol FF 3x6	61789- 40-0	0.0032	0.0419	Readily	71*	ECHA RD

¹⁰⁷ https://echa.europa.eu/documents/10162/13632/information_requirements_r10_en.pdf

¹⁰⁸ https://echa.europa.eu/documents/10162/13632/information_requirements_r7b_en.pdf

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Substance	Product	CAS	PNEC aqu (freshwat er) mg/L	PNEC soil (mg/kg soil dw)	Bio- degradation (... biodegradabl e in water)	Bio- accumul ation (BCF)	Reference
	Re-Healing Foam RF1 1%						
1,2-ethandiol	Moussol FF 3x6	107-21-1	10	1.53	Readily	waived	ECHA RD
	Orch dex BlueFoam 3x4						
Triethanolammo nium- laurylsulfate	Moussol FF 3x6	85665- 45-8	0.017	0.042	Readily	waived	ECHA RD
sodium decyl sulphate (-)	Re-Healing Foam RF1 1%	142-87-0	0.095	0.2445	Readily	waived	ECHA RD
amides, coco, N-[3- (dimethylamino) propyl] (-)	Re-Healing Foam RF1 1%	68140- 01-2	No data				
amides, coco, N- [3- (dimethylamino)p ropyl], N- oxides (-)sucrose (-)	Re-Healing Foam RF1 1%	68155- 09-9	0.0059	3.68	Readily	No data	ECHA RD
sulfuric acid, mono-C12-14- alkyl esters, compds. with triethanolamine (-)	Re-Healing Foam RF1 1%	90583- 18-9	0.012	0.083	Readily	No data	ECHA RD
1-Propanaminium,N- (carboxymethyl)- N,N-dimethyl-3- [[{(3,3,4,4,5,5,6,6, 7,7,8,8,8- tridecafluorooctyl) sulfonyl]amino]- ,inner salt	AFFF	34455- 29-3	0.0326	0.00133	Not readily	450	ECHA RD
1-Propanaminium, 3-amino-N- (carboxymethyl)- N,N-dimethyl-N- [[{(gamma-omega- perfluoro-C6-C16- alkyl)thio]acetyl] derives., inner salts	AFFF	80475- 32-7	0.009	1.17	Not readily	No data	ECHA RD

Explanatory note: Waived means, that the test was not required due to the results of other tests.

*An asterisk means, that this value was extrapolated based on calculations.

It is observable that the two fluorinated substances (CAS 34455-29-3 and 80475-32-7) are the only substances that are “not readily biodegradable in water” (data on biodegradation in soil is

not available in the registration dossier)¹⁰⁹. In addition, the substance with CAS 34455-29-3 also has the lowest PNEC for soil, meaning that, at concentrations higher than 1,33 µg/kg (ppb) a risk cannot be excluded. The combination of this value and with its relatively low PNEC for freshwater (0.0326 mg/l), shows, that this substance exhibits more hazard to the environment than any of the non-fluorinated substances. This finding is also supported by the fact that the treatment at WWTPs is ineffective (as shown in the previous subchapter). In terms of partitioning the fluorinated substance CAS 34455-29-3 has a log K_{oc} of 1.5, suggesting strong partitioning to treated effluent within WWTPs and release to surface water. Use during live incidents is assumed to be released equally to surface water and soil. This may suggest that the bigger impact for soils would come from live incidents.

However, some of the alternatives have both relatively low PNECs and relatively high biodegradation and/or bioaccumulation data. This is true for two alcohols (1-dodecanol and 1-tetradecanol). However, in comparison to the two fluorinated substances listed in the table above, both of the non-fluorinated substances are readily biodegradable due to the rapid metabolism of long-chain fatty alcohols in fish, mammals and microorganisms (based on information taken from their registration dossiers). That means that, even if the substance is emitted to the environment in the context of a release from WWTPs or live incidents, it will be biodegraded rapidly. Furthermore, as highlighted in the previous section, based on these properties it could be expected that waste water treatment plants would have a high level of efficacy for the destruction of these substances.

Taken together, this review of hazards based on PNECs and data on biodegradation and bioaccumulation shows, that the two fluorinated substances should be considered of higher priority compared to the non-fluorinated substances when it comes to hazards and potential risks to the environment. This is due to the PFAS being both non-biodegradable and having relatively low PNECs for water and soil. Some of the alternative substances exhibit low PNECs, however, this needs to be considered in the context of their ready biodegradation. Further discussion on the hazards of the shortlisted alternatives can be found in Section E.2.

B.5.1. Toxicokinetics (absorption, metabolism, distribution and elimination)

Not assessed in this study.

B.5.2. Acute toxicity

Not assessed in this study.

B.5.3. Irritation

Not assessed in this study.

¹⁰⁹ <https://echa.europa.eu/de/registration-dossier/-/registered-dossier/17549/1>

B.5.4. Corrosivity

Not assessed in this study.

B.5.5. Sensitisation

Not assessed in this study.

B.5.6. Repeated dosed toxicity

Not assessed in this study.

B.5.7. Mutagenicity

Not assessed in this study.

B.5.8. Carcinogenicity

Not assessed in this study.

B.5.9. Toxicity for reproduction

Not assessed in this study.

B.5.10. Other effects

Add text

B.5.11. Derivation of DNEL(s)/DMEL(s)

B.6. Human health hazard assessment of physicochemical properties

Not assessed in detail, see explanation in B.5.

B.7. Environmental hazard assessment

Not assessed in detail, see explanation in B.5.

B.8. PBT and vPvB assessment

Not assessed in detail, see explanation in B.5.

B.9. Exposure assessment

B.9.1. General discussion on releases and exposure

An exposure assessment was not in the scope of this study. However, Section B.9 presents estimates of the emissions of PFAS and of the constituents of the alternative fluorine-free fire-fighting foams to the environment, broken down by environmental compartment (Section B.9.3)

and discusses the possible uptake by humans via the consumption of food and water (Section B.9.6).

B.9.1.1. Summary of the existing legal requirements

See Section 1.3.3.

B.9.1.2. Summary of the effectiveness of the implemented operational conditions and risk management measures

See Section 1.3.4.

B.9.2. Manufacturing

As discussed previously, this dossier focuses on the use of PFAS in fire-fighting foams. The manufacturing of PFAS has not been considered. However note that emissions from the formulation of PFAS-based fire-fighting foams are considered within the following section.

B.9.3. Use 1: Fire-fighting foams

B.9.3.1. General information

The assessment is focused on the estimation of the emissions of PFAS and of the constituents of the alternative fluorine-free fire-fighting foams to the environment, broken down by environmental compartment (atmospheric, aquatic, and terrestrial environments) and the possible uptake by humans via the consumption of food and water.

The assessment focused on understanding the emission pattern throughout the life cycle so that releases can be compared across foam products: how much foam is used; how much of it is collected; how much is then incinerated; do the foams contaminate other environmental compartments and if so, how much ends up in each compartment.

Therefore, rather than using risk assessment models such as EUSES, a source-flow approach has been applied.

Due to the persistent nature of PFAS and non-threshold effects, releases of PFAS are of primary importance, and these are to be considered a proxy for exposure. The focus was on releases and to compare those amongst PFAS-based foams and the alternatives.

The emission estimates that have been developed are intended to provide an illustrative assessment to help better understand the material flow and key emission compartments. The findings presented here are not a detailed risk assessment and are not presented within any geographical disaggregation based on identified sites in the European Union)

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B.9.3.2. Approach

B.9.3.2.1. Development of the source-flow model

Based on guidance from ECHA, the UNECE inventory guidebook¹¹⁰, and OECD Emission scenario document for AFFF a basic source-flow model has been developed to make use of the data from the market analysis and substance identification (as a Microsoft Excel workbook). The development of this source-flow approach began with a consideration of what might be the key life-cycle stages and what kinds of emissions may occur at each life-cycle stage, which has incorporated the approach used within the PFOA restriction dossier under REACH.

Based on this analysis the model development began with four basic life-cycle stages where it was possible for emissions to occur, or material to flow through into the next life cycle stage:

- **Formulation of the fire-fighting foam concentrate.** This includes consideration of the PFAS and fluorine-free substances used as surfactants within the foam concentrate. Note, that it was assumed that the life-cycle begins at this stage rather than the manufacture of the surfactants themselves. This distinction is made on the basis that the manufactured surfactants may have multiple applications, not limited to only fire-fighting foams. The full range of possible applications for a given PFAS or fluorine-free surfactant is outside the scope of the current study.
- **Storage.** Storage is considered a key life cycle stage with quantities of foam concentrate reaching expiry before active use¹¹¹. During storage of foam concentrate it may be possible for leaks or spillages to occur, which directly contribute to environmental emissions. However, for usage sites (airports, refineries, terminals, industrial sites and military sites), appropriate risk management systems will generally be in place meaning that such leaks/spillages can be contained from direct release and will more likely act as an input to the waste/waste water system (e.g. sewers). Efficacy and management of materials put to sewer are further managed under waste.
- **In-use.** Active use of fire-fighting foams forms likely the most important life-cycle stage. The model developed defines two types of use. Firstly 'training' exercises, which are assumed to happen within contained conditions (i.e. bunding / capture systems are in place to capture and retain runoff)¹¹²; and secondly 'live' incidents which assumes no containment and full loss to the environment (following the approach adopted with the PFOA Annex XV dossier)¹¹³.
- **Waste.** The waste cycle includes two key pathways. Firstly, incineration of any expired stocks of foam concentrate. Secondly waste water treatment works processing of materials from leaks/spillage during storage, plus some runoff from training exercises.

Formulation of the fire-fighting concentrate

¹¹⁰ <https://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emissions-inventory-guidebook/emep>

¹¹¹ BiPRO, 2010, Study on waste related issues of newly listed POPs and candidate POPs – comments that the average lifespan of firefighting foams is 15 years.

¹¹² It is recognised based on the stakeholder engagement that the standard of containment for training run-off has in the past not been optimal. However, because of the concerns raised around substances such as PFOS, it can be expected that the standards in use currently are a significant improvement upon standards from the early 2000s.

¹¹³ ECHA, 2018, 'Background document - to the Opinion on the Annex XV dossier proposing restrictions on Perfluorooctanoic acid (PFOA), PFOA salts and PFOA-related substances', ECHA/RAC/RES-O-000006229-70-02/F and ECHA/SEAC/RES-O-000006229-70-03/F

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The model has been designed to allow calculation of both quantities of fire-fighting foams manufactured within the European Union, and quantities of finalised fire-fighting foam concentrate imported and used in the EU. Only quantities manufactured within the European Union are assumed to lead to emissions and exposure at the formulation stage.

The PFOA Annex XV dossier assumes default worst case emission rates of 2.5% w/w to air, 2% w/w to water (assumed to be waste water system rather than direct release) and 0.2% to soil as a direct release from spillages / deposition during manufacture. In the absence of better data, the same release rates have been applied to the non-fluorinated alternatives.

Storage

Following manufacture and sale, the fire-fighting foam concentrates will pass into the storage phase of the life-cycle. A proportion of the annual sales will also go directly into use (see in-use phase), with the remainder held in store, sometimes for several years. Data on leakage rates / spillages was not identified during the study, and therefore a value based on expert judgement of 1% of total stocks has been applied.

In-use phase

The "in-use" phase of the model was then further refined to incorporate different kinds of use and application and how these may affect the type of emission and usage rate (i.e. use at airports vs municipal fire brigades for example). This included data from Eurofeu (see Annex A) on industry sector splits, and [usage information from several stakeholders. In their study, Wood \(2020\) used annual usage rate](#) data from Brooke et al (2004)¹¹⁴ which highlighted that most of the fire-fighting foam in the private sector is used for training (93% w/w). In the absence of better data, it was assumed that, for public fire brigades, use will predominantly be focused on live incidents with a smaller quantity used for training, assumed to be 93% on live incidents and 7% on training.

[Wood \(2000\) used for annual foam use rate](#) ~~data~~ data from BiPRO (2010)¹¹⁵ and Buser et al (2009)¹¹⁶ which quote usage rates of between 15% and 20% annually¹¹⁷. [However, several industry stakeholders provided comments on the PFHxA restriction proposal¹¹⁸ and during the](#)

¹¹⁴ Brooke et al (2004), "Environmental risk evaluation report: Perfluorooctanesulphonate (PFOS), Report produced for the England and Wales Environment Agency.

¹¹⁵ BiPRO (2010), "Study on waste related issues of newly listed POPs and candidate POPs", Commission report under framework ENV.G.4/FRA/2007/0066.

¹¹⁶ Buser et al (2009), 'Substance flow analysis of PFOS and PFOA in Switzerland. Environmental Studies 0922. Federal Office for the Environment, Bern.

¹¹⁷ BiPRO 2010 base their estimates on usage rates against a survey of UK fire authorities completed by RPA in 2004. This suggested that annually 15% of total stocks are used across all sectors (public and private). Usage rates by municipal fire and rescue services were higher at between 40% and 50%. Buser et al 2009 base their estimates on remaining stocks of PFOS within all sectors (public and private services) using 20% of all stocks annually. To maintain a steady flow of business it is assumed that both public and private brigades will replace stocks as use occurs, so replacement foam would be purchased annually.

¹¹⁸ See <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

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preparation of the present restriction proposal on firefighting foams that these figures are outdated. Instead, they provided alternative estimates.

Eurofeu clarified (Eurofeu consultation, February 2021) that in 2004 no restriction on the use of AFFF were in place and fire trainings were not as restricted as today hence were very common and broadly done by all fire brigades. According to Eurofeu, since the first restriction of PFOS the situation changed, foam is only used if ultimately necessary, municipal brigades mostly dealing with a fire incident first with water and only lately with foam, if needed. Trainings on live fires are extremely rare, very expensive and only possible in specific places, most of which in the meantime do not allow using fluorine containing foams. So-called "cold" foam trainings (no fires, foam application training only) are done in the vast majority of cases using "training foams" which are fluorine-free.

Eurofeu reported that users from the petrochemical industry indicate that less than 10% of the foam they have on stock is being used in incidents (fires, precautionary foam application and unintended releases from malfunctions) (Eurofeu consultation, February 2021).

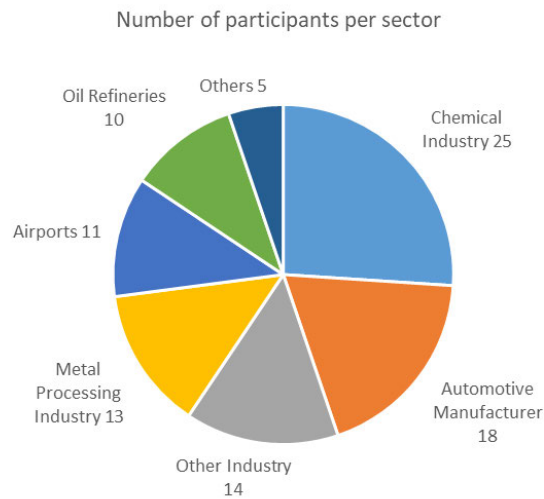
The Firefighting Foam Coalition (FFFC) indicates in their comment to the PFHxA restriction proposal¹¹⁹ that a 2011 update of the AFFF inventory report estimated that annual AFFF use in the United States for the years 2004-2011 was 8% of the total stock¹²⁰. As foam uses and practices are similar between the US and EU, FFFC believes that a foam use rate of about 8-10% is a reasonable estimate for the EU during this time period. FFFC however adds that "if 8-10% of foam stocks were being used each year during a period before best practices were implemented or required, use rates for the next 5 years would be expected to be much smaller, maybe as low as 3-5%".

WFVD, the German Industrial Fire-Fighters Association carried out a survey in summer 2020 on the use of fire-fighting foam by industrial fire services in Germany and submitted the report during the consultation of the PFHxA restriction proposal¹²¹. The survey had a response rate of 12.3% with a total of 96 responses having been included in the report. Remarkably, eight of the ten largest German airport fire services and ten of twelve oil refinery fire services responded to the survey. The share of respondents per sectors is indicated in the below figure.

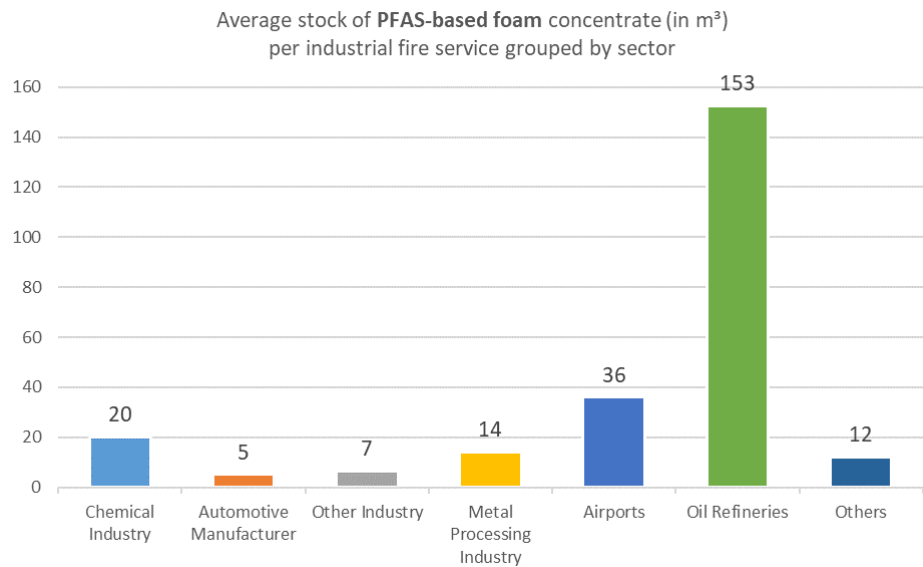
¹¹⁹ Comment 3010 in Part 2 document available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

¹²⁰ <https://www.informea.org/sites/default/files/imported-documents/UNEP-POPS-POPRC13FU-SUBM-PFOA-FFFC-3-20180112.En.pdf>

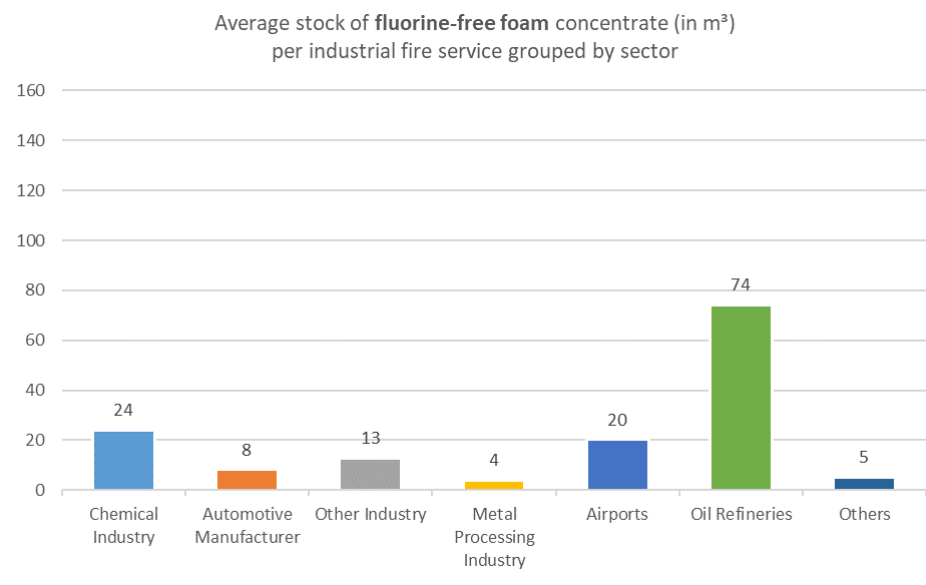
¹²¹ WFD comment 3158 to the PFHxA restriction proposal – available in Part 5 document at <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>



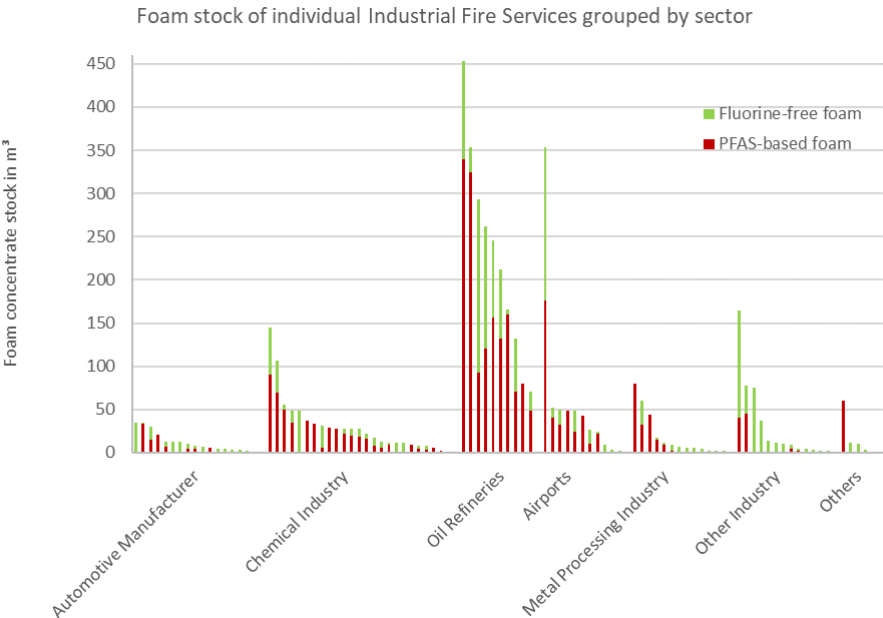
The survey results indicate that the industrial fire services of the refineries have by far the largest average amount of foam, both fluorine-free and PFAS-based foam. This is followed by the industrial fire services of airports and the chemical industry.



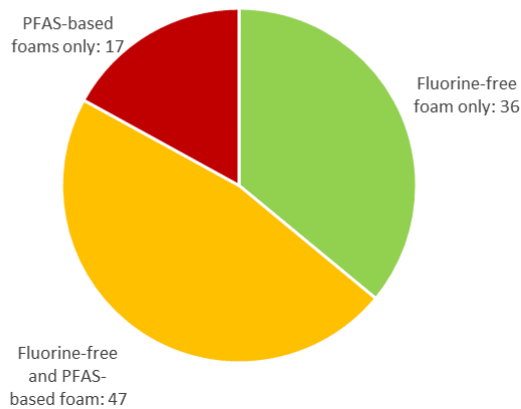
ANNEX XV RESTRICTION REPORT – PFAS IN FIREFIGHTING FOAMS



The survey shows that most fire services are providing PFAS-based as well as fluorine-free foam concentrate. 47% of the responding industrial fire services have both types of foam concentrate available, 36% of the industrial fire services only use fluorine-free foam and 17% only use PFAS-based foam.

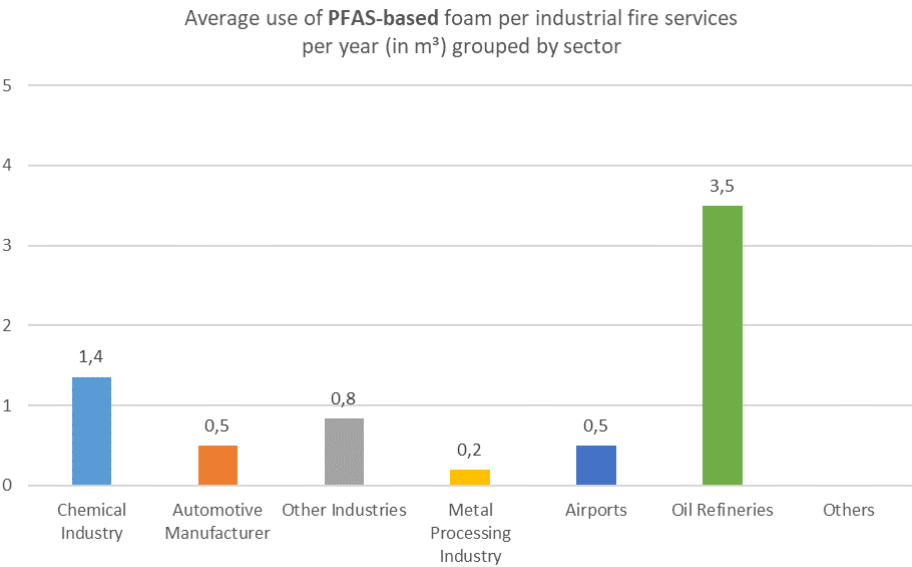


Foam concentrate stocks at Industrial Fire Services in Germany (expressed as a percentage)

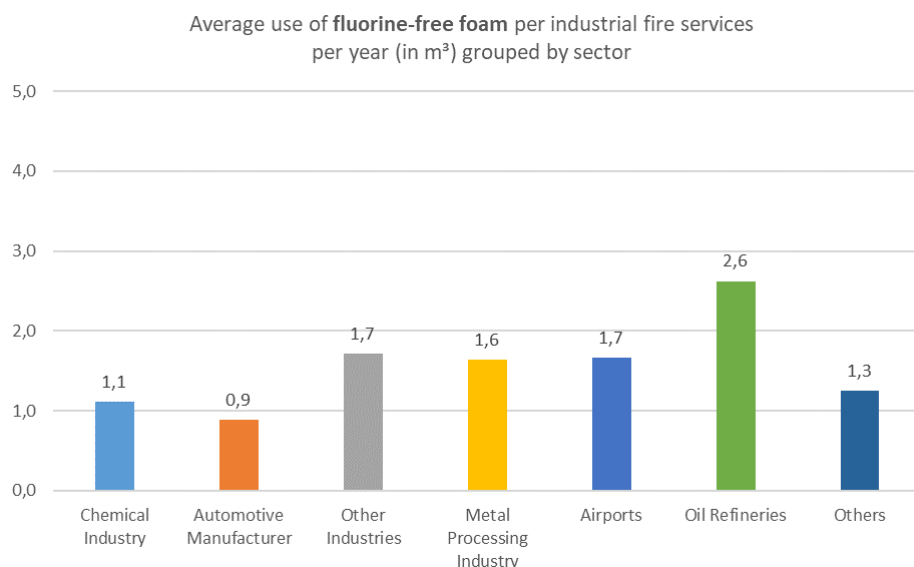


The use of foam concentrates in German industrial fire services

WFD indicates that the results for the average amount of PFAS-based and fluorine-free foam used per year and sector show that foam is used relatively rarely. Especially when the numbers are put in relation to the average stock, it becomes clear that the use of foam is not commonplace, even at industrial fire services. However, WFD highlights that it must also be considered that in a major incident, very large quantities can be used at once – a circumstance that could not be adequately taken into account in this survey and through the presentation of average values (the question referred to the last five years as the observation period for specifying the average value).



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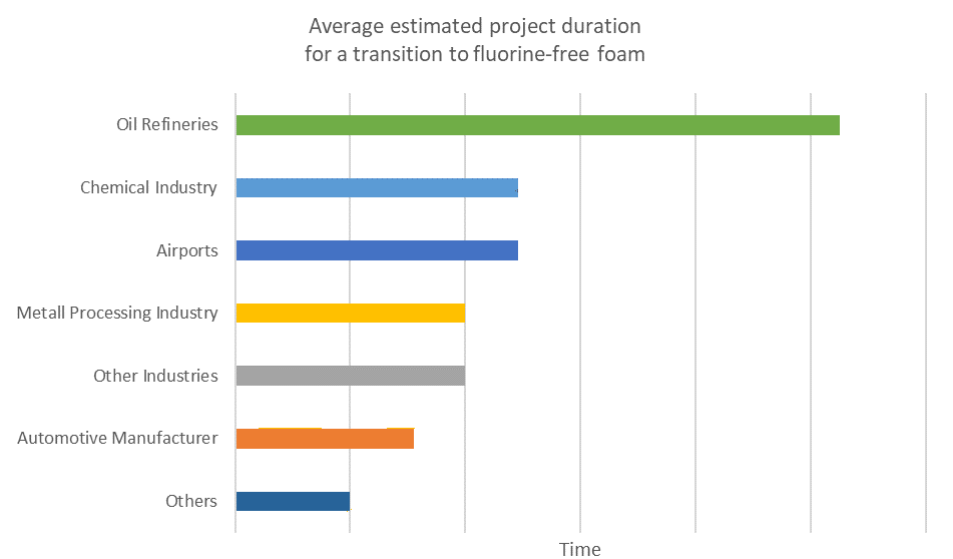
However, from the stocks of PFAS-based foam and annual use indicated above, average annual use rates per sector can be derived and are below 12%:

Sector of use	Stock of PFAS foam (m ³)	Annual use (m ³ /y)	Annual use rate, compared to stock (%)
Chemical industry	20	1.4	7.0
Automotive manufacturers	5	0.5	10.0
Metal processing industry	14	0.2	1.4
Airports	36	0.5	1.4
Oil refineries	153	3.5	2.3
Other industries	7	0.8	11.4

How long will the transition take?

The chart of the mean estimated time it takes to transition to fluorine-free foam concentrate shows that more time is required, especially for the refineries. The other industries all indicate a similar duration of about 2 years for the changeover. However, it should be taken into account that the question was about the duration of the project,

i.e. from the time of the decision to change. Therefore, the values provided below should be interpreted in relation of each other and not in absolute values.

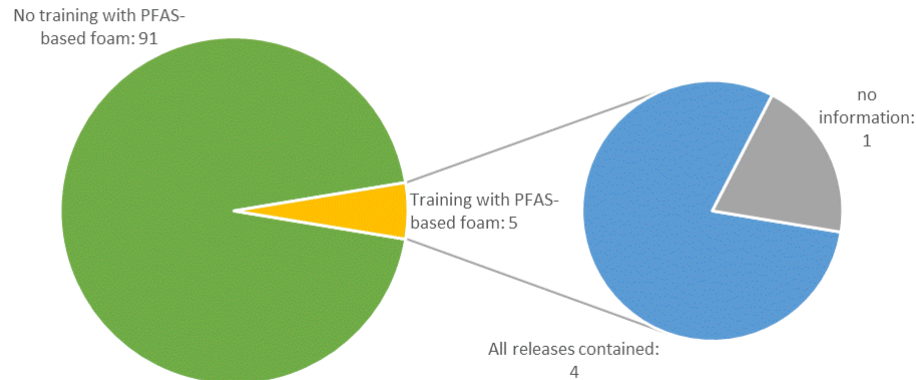


Training and tests

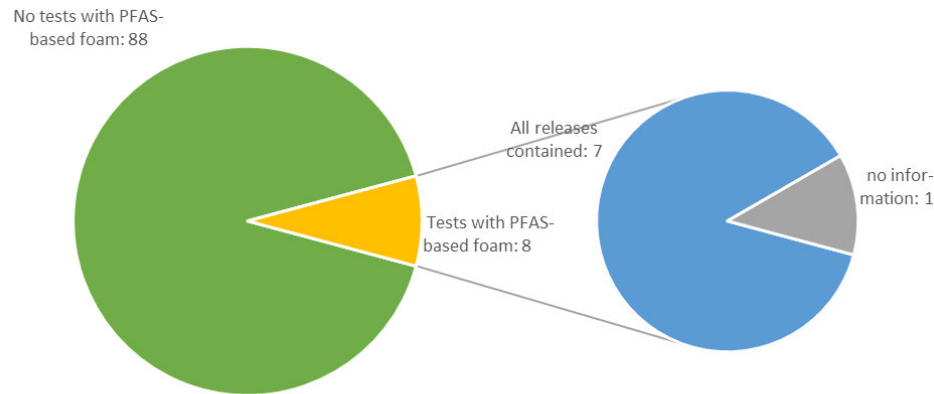
Training of emergency personnel and tests of extinguishing systems, vehicles or other mobile equipment hardly ever take place with PFAS-based foam concentrate. Those industrial fire services that are still practicing with PFAS-based foam collect the contaminated extinguishing water and dispose of it properly.

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Do you use PFAS-based foam to train emergency responders?
Do you contain all releases of fire water and dispose it?



Do you use PFAS-based foam to test extinguishing systems or mobile equipment?
Do you contain all releases of fire water and dispose it?



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The source-flow model therefore assumes usage rates of 17.5% for the majority of sectors. However, for the public fire service sector a usage rate of 50% per annum has been used¹²². The justification for this modification is that based on a survey of UK fire authorities public fire services primarily use fire-fighting foams for live incidents a quicker turnaround of stockpiles may be expected. A usage rate of 50% assumes a high rate of use for quantities purchased annually, with stockpiling of 50% to safeguard against larger emergency events where greater quantities of foam may be needed.

Commented [MD49]: This needs to be updated based on data and assumptions.

Finally, for training exercises, a factor has been added for the efficacy of bunding / control measures designed to manage run-off of fire-fighting waters during the training exercise. Extremely limited data was available on these aspects and therefore best estimates have been made based on expert judgement. Efficacy of the bunding for terrestrial applications was extrapolated to estimate ranges from 90-97% (assuming captured waters are passed to sewer / on site waste water treatment)¹²³, while for marine applications it is assumed all run-off is permitted to be released directly to sea with no capture and control. For live incidents we have used the values quoted within the REACH Annex XV dossier for PFOA, which assumes a 100% release (which should be considered a worst-case scenario), split evenly between surface waters and soil. Table B.1 provides further details of how quantities of fire-fighting foam has been manipulated.

Table B.1 Industry splits and usage rates based on data from Eurofeu and Brooke et al (2004)*

Sector	Percentage share of total	Annual usage rates (of total quantity sold annually)	Live incidents (as a percentage of total use)	Training (as a percentage of total use)	Efficacy of bunding/control measures for training
Military	6%	17.5%	7%	93%	90%
Civil Aviation	9%	17.5%	7%	93%	97%
Municipal Fire Services	13%	60%	93%	7%	90%
Chemical/petrochemical	59%	17.5%	7%	93%	97%
Marine Applications	12%	17.5%	7%	93%	0%
Ready to use applications	1%	17.5%	100%	0%	N/A

Commented [MD50]: These annual usage rates will be updated based on new data to be submitted by stakeholders.

*For live incidents a 100% release is assumed split evenly between releases to surface water and soil. In the case of marine applications this is a 100% release to sea.

Waste phase

All material not lost directly to the environment during use will enter the waste phase through a variety of pathways (i.e. capture of run-off; spillages/leaks during storage entering on-site

¹²² RPA, (2004), "Risk reduction strategy and analysis of advantages and drawbacks for PFOS", Report on behalf of Defra.

¹²³ Responses from the stakeholder engagement stated that 100% of training run-off is expected to be captured and retained, however, further statements from fire-fighters indicated that full capture is challenging and not always possible. The model therefore makes an assumption that minor losses will occur equivalent to 3% in the best cases, and at worst 10% for sectors with less well-defined sites of use and capture.

drains; unused foam concentrate which has expired), highlighting this phase's importance in the overall control and release to environment. The waste phase of the model aggregates the quantities of specific substances from different pathways to calculate total quantity per substance within the overall waste phase. This is then managed either by incineration (for end of life unused stocks) or waste water treatment works for retained runoff, losses to sewer from spillage/leakage during storage¹²⁴. The model then applies two factors, firstly a distribution factor (as K_{oc} ¹²⁵) taken from REACH registration dossiers to understand how the substance partitions between liquid and sludge phases of the waste water process. Then secondly an efficacy factor is applied to reflect how successfully the waste water process destroys the substance, and how much remains unchanged as a direct release to environment.

Data on the efficacy of waste water treatment works against named substances was very limited for non-fluorinated alternatives. For the PFAS-based surfactants used in fire-fighting foam concentrates the efficacy is expected to be very low. The model assumes an efficacy of zero with all PFAS substances passing to environment unchanged. For the hydrocarbon-based alternatives, some are readily biodegradable, while others with more complex organic structures may be more resistant to degradation. For non-fluorinated alternatives the efficacy ranges from 99% for substances such as alcohols, and as low as 50% for aromatics.

The model assumes all waste sludges are then applied to farmland as a release to soil. Note, that while we recognise that this is a common waste management practice for sewage sludge, this is not the case across the EU (for example the application of sewage sludge to land in Denmark is banned). The model acts as a high-level assessment of which compartments are the most important for emissions and key variables affecting emissions. No geopolitical splits are applied to the data for importance of environmental compartments in different Member States.

In terms of the proportion of material sent to waste water treatment works and proportion sent for incineration, only limited information was available. It is assumed that all retained run-off water, and losses from spillage/leakage to drain on controlled sites are sent to either onsite WWTWs or municipal WWTWs dependent on the site. The use of incineration would be retained for unused expired fire-fighting foam concentrate, but on this matter, there is conflicting information. (A number of references (RPA, 2004; Buser et al 2009; and BiPRO, 2010) suggest usage rates of around 15-20% of existing stocks per annum, with an AFFF shelf-life of up to 15 years, which would suggest all foam concentrate is used before expiration (on average). Discussions held at the 2018 POPs Review Committee (POPRC) meeting on exemptions for PFOA (its salts and related-compounds), included comments from a number of NGOs that significant quantities of expired foam concentrate was destroyed, particularly from private fire brigades, where live use was much less common.

The assumed usage rate of 15-20% per annum of existing stocks is an average across all sectors of use. This means that there will be installations with potentially far lower usage rates annually, increasing the potential for quantities to reach expiry before use. However, no data has been identified to quantify the amounts sent for incineration beyond commenting that waste water

Commented [MD51]: To be updated w th new stakeholders' figures.

¹²⁴ It is assumed that the sites in question will store these materials in secure areas with either bunding or on-site drainage. If there is a spillage/leak it is assumed that it will be contained and enter the waste systems.

¹²⁵ K_{oc} = Is a normalised partition coefficient used to calculate how much of a given substance will adsorb to organic matter. It is used as a measure for mobility of a given substance (primarily within terrestrial environments) but can be used as a measure of partitioning between liquid phases and organics within a wastewater treatment works.

treatment is likely to be the dominant method for management of material in the waste cycle based on the outputs of the source-flow calculations. The model developed for the current study is a high-level assessment using the available references (including usage rates and shelf-life) meaning that the model assumes no material is sent for incineration.

Section E.4 (subsection j. Emissions from disposal of legacy foams) provides some further insight to incineration of PFAS. This notes that, in general, PFAS emissions from incineration are not well studied. However, the chemistry of PFAS makes it resilient to thermal destruction. The US EPA (2019)¹²⁶ comments on studies (from 2004 and 2014) that showed for PFOA temperatures of 1,000 Celsius and residence time of 2 seconds were sufficient to destroy the PFOA. Kemi (2016)¹²⁷ comments that more widely for PFAS compounds temperatures of at least 1,100 Celsius are needed, and that longer-chain PFAS species are more readily destroyed (potentially breaking down to shorter chain PFAS compounds), with the CF₄ species the most resilient. For CF₄ chemistry temperatures of 1,400 Celsius are required, with the breakdown products including carbon dioxide and hydrogen fluoride.

As a side note, the industrial emissions directive (2010/75/EU) requires waste incineration plants to operate at temperatures of at least 850 Celsius with residence time of at least two seconds. This would cover standard municipal waste incineration plants. For elevated temperatures >1,000-1,400 Celsius this is likely to require more specialised commercial hazardous waste incineration, noting that a more limited fleet of specialised high-temperature operators exist across Europe.

Summary of assumptions applied in the model

Table B.2 provides a summary of all factors applied within the model that manipulates the flow of substances from formulation to waste cycle, including emissions at different life-cycle stages. [The Excel sheet with the underlying calculations is available at the end of this section.](#)

Table B.2 Summary of factors applied to data

Life cycle stage	Description	Value	Reference
Formulation	Emissions during formulation of fire-fighting foam concentrates	2.5% w/w to air; 2% w/w to waste water; 0.2% to air	PFOA Annex XV dossier – assume same values for non-fluorinated alternatives.
Storage	Lifespan of concentrate	15 years	BiPRO (2010)
Storage	Annual leak rate / spillage	1% w/w of total stocks	Assumed value based on expert judgement.
In-Use - Training	Industry sector splits	See Table B.1	Eurofeu and Brooke et al (2004)

¹²⁶ US EPA, 2019, 'per and polyfluoroalkyl substances (PFAS): Incineration to manage PFAS waste streams', USEPA innovation report.

¹²⁷ <https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-highly-fluorinated-substances-pfas.pdf>

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In-Use - Training	Usage rates annually	See Table B.1	BiPRO (2010) and Posner (2019)
In-Use - Training	Efficacy of capture systems for run-off	See Table B.1	Assumed value based on expert judgement.
In-Use - Live incidents	Emission to environment	Assumed to be 100%; 50% surface water, 50% soil. For Marine applications 100% sea.	PFOA Annex XV dossier.
Waste cycle	Efficacy of incineration	99%. Note for PFAS based foams could be lower, but in lieu of data assume 99% for all substances, and use of high temperature waste incineration	Assumed value based on expert judgement.
Waste cycle	Partitioning for liquid/sludge	Based on K _{oc} values per substance	REACH Registrations
Waste cycle	Efficacy of treatment	Varies. For PFAS based substances assumed efficacy is zero. For hydrocarbons assumed efficacy varies from 50% - 99% depending on complexity and physicochemical properties.	Feedback from workshop.
Waste cycle	Final disposal.	Assume treated effluent is direct release to surface water. Assume treated sludge is placed on farm land as direct release to soil.	Expert judgement.

B.9.3.2.2. Selection of products and substances for emission estimation

The selection process for named non-fluorinated substances was intended to identify those substances found in the products most commonly used, and where the hazards for human health and environment were of the greatest concern. To identify these substances a four-step process was followed as detailed below:

Step 1 – Collation of all substances

The outputs of the substance identification identified 168 non-fluorinated fire-fighting foam commercial products. In practice the surfactant action of the non-fluorinated products required the use of more than one substance, with most products therefore using a combination of named substances. Furthermore, the same substance is often found in multiple products across different manufacturers. However, the named substances identified could be broadly grouped into four categories (as identified in the substance identification):

- Proteins
- Siloxanes
- Hydrocarbons
- Detergents

Step 2 – Most common products

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Based on the market analysis and stakeholder engagement, the most commonly named products in use were given priority and screened in for the final selection. Based on analysis of the “screened in” set, the highest priority products (most commonly named five) were passed into the next phase. This included:

- Respondol ATF 3/6 – manufactured by Angus Fire.
- Moussol FF 3x6 – manufactured by [REDACTED]
- Orchidex Bluefoam – manufactured by Orchidee
- Re-healing foam RF11% - manufactured by Solberg
- Re-healing foam RF3x6 ATC – manufactured by Solberg

Step 3 – Final selection of substances

Once the prioritised set of products was identified, the composition of products was identified (using safety data sheets) and hazard classification based on CLP. Using this approach those substances with hazard classifications relating to human or environmental toxicity were selected for use in the source-flow model.

The table below provides details of the specific substances where emission estimates have been developed. Note where ranges have been provided the upper limit has been used for the calculations as a conservative estimate.

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Table B.3 Final selection of substances (substances highlighted in blue selected) – see also footnotes at end of table.

Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
Respondol ATF 3/6	1-dodecanol	Detergent	112-53-8	0.1 to 1	Eye Irritant. 2 Aquatic Acute 1 Aquatic Chronic 2	Short lived in air (<24 hours) and soil, likely to volatilise from water to air.
Respondol ATF 3/6	1-tetradecanol	Detergent	112-72-1	0.1 to 1	Eye Irritant. 2 Aquatic Chronic 1	Short lived in air (<24 hours) and soil (5.5 days), likely to volatilise to air from water and wet soil but remains in dry soil until degraded.
Respondol ATF 3/6	1-butoxy-2-propanol	Hydrocarbon	131-66-8	4 to 10	Skin Irritant. 2 Eye Irritant. 2	(E) Likely to be short lived in air and soil, as an alcohol it should denature in water and would be expected to volatilise.
Respondol ATF 3/6	Sulfuric acid, mono-C8-10 (even numbered)-alkyl esters, sodium salts	Detergent	5338-42-7	1 to 4	Skin Irritant. 2 Eye Damage. 1	ECHA database of registered substances under REACH (ECHA DB): Water: 92% degraded after 30 days.
Respondol ATF 3/6	1,2-propanediol	Hydrocarbon	57-55-6	4 to 10	Not classified	When released to air will exist solely in the vapour phase, half-life in air is short (32 hours), Highly mobile in soil, but less likely to volatilise, breakdown in soil processes important (<60 days). In water does not bind to suspended solids but remains in aqueous phase. Testing at WWTWs suggests readily breaks down in water.
Respondol ATF 3/6	Sodium laureth sulphate	Detergent	8891-38-3	to 4	Skin Irritant. 2 Eye Damage. 1 Aquatic Chronic 3	ECHA DB: notes that based on distribution modelling that the primary receiving environment is water. Based on REACH dossiers suggests it is readily biodegradable in water.
Moussol FF 3x6	ALKYLAMIDOBETAINES (SAME EC BUT OTHER CAS)	Detergent	61789-40-0	<5	Skin Irritant. 2 Skin Sensitiser. 1 Eye Irritant. 2 Aquatic Chronic 3	ECHA BD: Half-life in water (at 25C) is 15 days; in sediment at (at 25C) is 4.5 months. Half-life in soil (at 25C) is 30 days.
Moussol FF 3x6	1,2-ETHANDIOL	Hydrocarbon	107-21-1	<10	Acute Toxicity. 4 * STOT RE 2	When released to air will exist solely in vapour phase, half-life in air is short (48 hours), Highly mobile in soil, but less likely to volatilise, breakdown in soil processes important (half-life is <12 days). In water does not bind to suspended solids but remains in aqueous phase. Half-life in water was <14 days at 8 Celsius.
Moussol FF 3x6	2-(2-BUTOXYETHOXY)ETHANOL	Hydrocarbon	112-34-5	<10	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water.

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Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
Moussol FF 3x6	ALKYLAMIDOBETAINES	Detergent	147170-44-3	<5	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 Acute Toxicity. 4 STOT SE 3 (respiratory tract...) (Inhalation) Aquatic Chronic 3	ECHA BD: Half-life in water (at 25C) is 15 days; in sediment at (at 25C) is 4.5 months. Half-life in soil (at 25C) is 30 days.
Moussol FF 3x6	TRIETHANOLAMMONIUM-LAURYL SULFATE	Detergent	85665-45-8	<10	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 Acute Toxicity. 4 STOT SE 3 Aquatic Chronic 3	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Orchidex BlueFoam 3x4	107-21-1 Ethandiol (vgl. Glykol) 5 - < 10 %	Hydrocarbon	107-21-1	5 - < 10 %	Acute Toxicity. 4 * STOT RE 2	When released to air exists solely in vapour phase for air, half-life in air is short (48 hours), Highly mobile in soil, but less likely to volatilise, breakdown in soil processes important (half-life is <12 days). In water does not bind to suspended solids but remains in aqueous phase. Half-life in water was <14 days at 8 Celsius.
Orchidex BlueFoam 3x6	9 D-Glucopyranose oligomeric C10-16-alkyl glycosides	Detergent	110615-47-9	1 - < 5 %	Skin Irritant. 2 Eye Damage. 1	ECHA DB: Half-life in air <5 hours; fully biodegrades in water.
Orchidex BlueFoam 3x3	2-(2-Butoxyethoxy)ethanol	Hydrocarbon	112-34-5	15 - < 20 %	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water. (E) Only limited data available, review of multiple SDS all comment that this substance is readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Orchidex BlueFoam 3x5	Ammonium lauryl sulfate	Detergent	32612-48-9	1 - < 5 %	Skin Irritant. 2 Eye Irritant. 2	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Orchidex BlueFoam 3x7	Ammonium alkyl C10-C16 sulphate	Detergent	68081-96-9	1 - < 5 %	Skin Irritant. 2 Eye Dam. 1	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Re-Healing Foam RF1 1%	sucrose (-)	Hydrocarbon	57-50-1	>1%	Not classified	(E) Readily biodegradable.
Re-Healing Foam RF1 1%	1-propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-, N-cocoyl derivs., hydroxides, inner salts (-)	Detergent	61789-40-0	≤10%	Skin Irritant. 2 Skin Sensitiser. 1 Eye Irritant. 2 Aquatic Chronic 3	ECHA BD: Half-life in water (at 25C) is 15 days; in sediment at (at 25C) is 4.5 months. Half-life in soil (at 25C) is 30 days.

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Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
Re-Healing Foam RF1 1%	2-(2-butoxyethoxy)ethanol (01-2119475104-44)	Hydrocarbon	112-34-5	≤20%	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water.
Re-Healing Foam RF1 1%	sodium octyl sulphate (-)	Detergent	142-31-4	≤10%	Skin Irritant. 2 Eye Damage. 1	ECHA DB: Half-life in air 42 hours. Expected to fully biodegrade in water.
Re-Healing Foam RF1 1%	sodium decyl sulphate (-)	Detergent	142-87-0	<3%	Skin Irritant. 2 Eye Damage. 1 Aquatic Chronic 3	ECHA DB: Half-life in air 32 hours. Expected to fully biodegrade in water (92% after 30 days).
Re-Healing Foam RF1 1%	1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acyl derivs., hydroxides, inner salts (-)	Detergent	68139-30-0	≤10%	Eye Irritant. 2	ECHA DB: Will biodegrade in water, 71% degraded after 28 days at 20 Celsius.
Re-Healing Foam RF1 1%	amides, coco, N-[3-(dimethylamino)propyl] (-)	Detergent	68140-01-2	<0.2%	Skin Irritant. 2 Eye Damage. 1 Aquatic Chronic 1	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Re-Healing Foam RF1 1%	amides, coco, N-[3-(dimethylamino)propyl], N-oxides (-)sucrose (-)	Detergent	68155-09-9	≤1%	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 STOT RE 2	ECHA DB: Sewage sludge test showed 93% degradation after 28 days.
Re-Healing Foam RF1 1%	D-glucopyranose, oligomers, decyl octyl glycosides (-)	Detergent	68515-73-1	<3%	Eye Damage. 1	ECHA DB: half-life in air <5hours; In soil and water fully biodegrades based on OECD test protocols.
Re-Healing Foam RF1 1%	sulfuric acid, mono-C12-14-alkyl esters, compds. with triethanolamine (-)	Detergent	90583-18-9	≤10%	Acute Toxicity. 4 Skin Irritant. 2 Eye Damage. 1 Aquatic Chronic 3	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Re-Healing Foam RF1 1%	alpha-sulfo-omega-hydroxy-poly(oxy-1,2-ethanediyl), C9-11 alkyl ethers, sodium salts (-)	Detergent	96130-61-9	<3%	Pre-Registration process	(E) Would expect this compound to be readily biodegradable in water. Half-life likely to be days-weeks (<30 days)
Re-Healing Foam RF3x6 ATC	sucrose (-)	Hydrocarbon	57-50-1	>1%	Not classified	(E) Readily biodegrades
Re-Healing Foam RF3x6 ATC	2-(2-butoxyethoxy)ethanol	Hydrocarbon	112-34-5	≤20%	Eye Irritant. 2	Half-life in air is short (<5 hours). Within soils will be highly mobile but readily biodegradable. In water will not bind to suspended solids (remains in aqueous phase). Readily biodegradable in water.

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Product	Substance	Category	CAS number	Concentration in product % w/w	Hazard classification	Degradation and fate*
Re-Healing Foam RF3x6 ATC	Starch	Hydrocarbon	9005-25-8	>1%	Not classified	(E) B odegradable
Re-Healing Foam RF3x6 ATC	Cocamidopropyl hydroxysultaine	Detergent	68139-30-0	<2.5%	Eye Irr tant. 2	ECHA DB: Will biodegrade in water, 71% degraded after 28 days at 20 Celsius.

* All degradation and fate data is based on Pubchem (<https://pubchem.ncbi.nlm.nih.gov/>), the ECHA database of REACH registered substances (ECHA DB) (<https://echa.europa.eu/information-on-chemicals/registered-substances>), or in cases where no information was found had been based upon expert judgement (E)

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Step 4 Selection of PFAS substances

Additionally, based on the outputs of the market research (Annex A) and stakeholder engagement, the highest tonnage PFAS based substances were also selected for modelling in the source-flow model. This included the following two substances:

Table B.4 PFAS based substances for selection

Fluoro-compound	CAS number	Tonnes per year	Share of the total market
1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt	34455-29-3	21.1	6%
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	80475-32-7	17.2	5%

Extrapolation of activity data

The outputs from the market analysis (Annex A) provided valuable information on which non-fluorinated products are most commonly in use. However, data on specific quantities per product was largely incomplete. Therefore, a different approach was needed to help develop emission estimates. Data provided by Eurofeu (which represents 60-70% of foam producers) provided data for total quantities of PFAS-based and non-fluorinated based products as an aggregated total. This has been further extrapolated to derive estimated total EU sales of 20,000 tonnes of PFAS-based concentrate annually, and 9,000 tonnes of non-fluorinated alternatives annually (see Annex A).

The stakeholder engagement also identified 12 manufacturers of non-fluorinated alternatives. The aggregated 9,000 tonnes has therefore been allocated equally across all 12 manufacturers, and further disaggregated based on number of products per manufacturer.

This approach allows a fair assessment of the source-flow of material and order of magnitude estimates. The key limitation however is that some products will likely be used more widely than others. Suitable market data to provide specific quantities per product was unavailable.

B.9.3.3. Results and analysis

B.9.3.3.1. Key messages from emission source-flow model

The source-flow model has been used to produce emission estimates for 10 unique non-fluorinated substances (noting that two substances appear in multiple products, and further that alkylamidobetaine is listed with two different CAS numbers suggesting minor variation of the specific chemistry); as well as two PFAS-based substances.

The non-fluorinated alternatives include a combination of hydrocarbons and detergents as defined by the selection methodology. Table B.5 and Table B.6 provide summary overviews (as percentage ratios) of the key emission compartments and life-cycle stages for emissions.

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The initial overview of Table B.5 highlights that fresh surface water and soil are the key receiving environmental compartments. Furthermore, Table B.6 highlights that, for non-fluorinated substances, live incidents are the major point of release, while for PFAS the waste phase is the key life-cycle stage for emissions, primarily from losses associated with releases at WWTPs. The major reason for this difference is that, while non-fluorinated foams are readily expected to degrade within WWTPs (thus lowering the importance of the waste cycle), PFAS based foams are expected to undergo little or no degradation within WWTPs.

Table B.5 Overview of ratios for emissions by different environmental compartment for all life-cycle stages combined.

Substance group	Air	Fresh surface water*	Marine waters	Soil
Non-fluorinated alternatives (range)	9 – 18%	33 – 37%	10 – 15%	30 – 45%
Non-fluorinated alternatives (mean average)	14%	35%	13%	38%
1-Propanaminium, N-(carboxymethyl)-N,N-dimethyl-3-[[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-, inner salt	9%	51%	8%	32%
1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts	9%	30%	8%	53%

*includes releases from WWTPs after treatment.

Table B.6 Overview of ratios for emissions by different life-cycle stages

Substance Group	Formulation	Storage and Training	Live	Waste
Non-fluorinated alternatives (range)	9 – 18%	12 – 18%	40 – 62%	1% – 35%
Non-fluorinated alternatives (mean average)	14%	15%	52%	19%
PFAS based substances (mean average)	9%	9%	30%	52%

Further examination of the data helps elaborate on the summary findings within the two tables, with the following key points to help add context to the overview tables:

Management of runoff during training

The data from Brooke et al (2004) highlights that, aside from municipal fire brigades, the major use of fire-fighting foams is for training purposes. Feedback from the stakeholder consultation indicated that at least in some Member States and applications there will be local or national-level regulations in place governing containment and prevention of release of fire-fighting foam or firewater runoff to the environment, although it is not clear whether this is comprehensive. One possible exception is training for marine applications, where the more limited options likely means full loss of all firewater runoff to the marine environment.

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An assessment of potential treatment scenarios developed in the study¹²⁸ underlying this dossier suggests that for large infrastructure installations (e.g. airports, petrochemical facilities, and fire-fighter training complexes) the site should be engineered to allow for a 100% capture of materials used in the training activity. Furthermore, for live emergencies at such sites where larger volumes may be used and are expected to be handled, capture of firefighting water should be done as soon as practicable and safe. However, also note that, for live incidents, the releases of firefighting foams are very situation-specific and site-specific, and, in reality, it may not be possible to retain all runoff from fire-fighting.

The specific kind of engineered options (hard surfaces, bunded areas, on-site drainage systems, etc.) will vary from site to site and the specific kind of operation being undertaken. As a further example of the practical application of how a given site may be managed, the UNECE good practice guidelines provide some further insight¹²⁹:

“There are several possible types of systems for the retention of contaminated firefighting water. The systems can be installed permanently (i.e. pre-installed water barriers or permanent retention basins, if necessary with pumping installations) or be provided as mobile facilities (i.e. fire-fighting water barriers, hoods and sealing pads, mobile storage tanks).”

Firewater run-off can then be pumped into tanks and transported e.g. by trucks to treatment facilities. There are several short case studies of fire incidents with a description of retention and disposal of fire-water in Annex 1 of the UNECE good practice guidelines.

One further consideration is the management of fire-fighting foam or firewater runoff at either on-site waste water treatment works or municipal waste water treatment plants. Again, this is likely to vary from site to site and is determined in part by the frequency of training and quantities of material that need to be managed. On-site treatment plants would incur a significant cost in the construction and operational phases, as well as requiring a minimum level of throughput to make operations practical. In some cases (e.g. petrochemical works) it is possible that sites already have on-site WWTPs for other purposes and are able to manage firewater runoff as and when needed. In other cases where training is less frequent (e.g. only quarterly / twice a year) use of municipal waste water treatment plants under environmental permitting is more likely.

However, also note that where firewater runoff enters drains and is sent to municipal waste water treatment plants, the environmental permits may require some pre-treatment steps. For example, these could include the use of sediment traps to remove solids, an oil/water separator and possibly a granular activated carbon filter before discharge.

As a conclusion a distinction needs to be drawn between uses for training purposes and uses for live incidents, noting the potential for greater control over runoff from training compared to live incidents. A review of the evidence suggests that at national level there are regulations in place in several countries over the design and management of fire-fighting runoff for training, and best practice guidelines for live incidents. However, further data on how

¹²⁸ See Section 6 in: Wood, Ramboll, COWI: “The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report”. Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

¹²⁹

https://www.unece.org/fileadmin/DAM/env/documents/2017/TEIA/JEG_MTGS/UNECE_Safety_Guidelines_and_Good_Practices_for_Fire-water_Retention_14_Nov_2017_clean.pdf

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comprehensive the coverage of these measures is across the whole EU and their practical implementation has been more difficult to obtain, and, based the evidence analysed, it is not possible to conclude that substantial quantities of runoff could not be released to the environment across Europe, particularly from live incidents..

Processing of substances in waste water

Once within the waste water process two key factors determine how the substances identified are managed. Firstly partitioning (as K_{oc}) and secondly the efficacy of the works to successfully destroy the chemical before release. The Log K_{oc} values have been used a measure to help understand partitioning. In practice, the lower the K_{oc} Value the more 'water-loving' the substance, and the less likely it is to partition into the sludge phase. Table B.7 provides log K_{oc} values for a range of substances to provide an indicative guide.

Table B.7 log K_{oc} values for a set of solvents, POPs and PFAS based substances as indicative guide to partitioning against K_{oc} values.

Substance	Substance type	Log K_{oc} (l/kg)	Partitioning
Acetone	Solvent	0.24	Hydrophil c
Butanol	Solvent	0.84	Hydrophil c
Perfluorobutane sulfonic acid (PFBS)	PFAS	1.0	Hydrophil c
Perfluorooctanoic acid (PFOA)	PFAS / POP	1.3 – 2.4	Hydrophil c
Perfluorohexane sulfonic acid (PFHxS)	PFAS / cand date POP	1.8	Hydrophil c
Perfluorooctanesulfonic acid (PFOS)	PFAS/POP	2.5 - 3.1	Mixed
Endosulfan	Pesticide / POP	3.3	Mixed
Endrin	Pesticide / POP	4.09	Hydrophob c
Methoxychlor	Pesticide / Cand date POP	4.9	Hydrophob c
Polychlorinated biphenyls (PCBs)	POP	5.5	Hydrophob c
Poly aromatic Hydrocarbons (PAHs)	POP	6.2	Hydrophob c

Table B.8 log K_{oc} values for non-fluorinated substances included within this assessment

Substance	CAS number	Log K_{oc} (l/kg)	Partitioning
1,2-ETHANDIOL	107-21-1	0.0	Hydrophil c
Triethanol Ammonium-Laurylsulfate	85665-45-8	1.88	Hydrophil c
sodium decyl sulphate (-)	142-87-0	2.09	Mixed

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Sodium laureth sulphate	68891-38-3	2.20	Mixed
Alkylamidobetaine	147170-44-3	2.81	Mixed
sulfuric acid, mono-C12-14-alkyl esters, compds. with triethanolamine (-)	90583-18-9	3.19	Hydrophob c
1-dodecanol	112-53-8	3.30	Hydrophob c
amides, coco, N-[3-(dimethylamino)propyl] (-)	68140-01-2	3.82	Hydrophob c
amides, coco, N-[3-(dimethylamino)propyl], N- oxides (-)sucrose (-)	68155-09-9	3.82	Hydrophob c
1-tetradecanol	112-72-1	4.53	Hydrophob c

Table B.8 provides the log K_{oc} values for non-fluorinated substances which range from 1.8 to 4.5, with the exception of 1,2 ethanediol which has a K_{oc} value of zero. This means that while these substances are soluble, for many of them there is a greater tendency to partition to the sludge phase. The log K_{oc} values for the two PFAS species are 1.5 and 3.8, which means the partitioning is more mixed, with the CAS 34455-29-3 species having much greater solubility and mobility. This places greater onus on the releases from WWTPs, noting that the efficacy of WWTPs for PFAS based substances is expected to be poor.

The other major factor is the efficacy of the works itself to irreversibly destroy specific substances. For the hydrocarbon-based alternatives, waste water treatment works could be expected to have a high level of efficacy, particularly against substances like 1,2 ethanediol which will readily disassociate. For detergent-based alternatives the efficacy may be less than for hydrocarbons, although overall efficacy is expected to be high ($\geq 70\%$). By contrast waste water treatment efficacy against PFAS substances is expected to be poor with close to zero effectiveness. This makes partitioning particularly important for evaluating final emission of PFAS substances.

Summary conclusions

The overviews presented within Table B.5 and Table B.6 illustrate that significant use occurs for training purposes, with an assumption applied that runoff is largely retained and treated within waste water treatment works (although also noting that feedback from the study workshop and literature review highlights efficacy of WWTPs for PFAS substances is poor). For the non-fluorinated alternatives, the effectiveness of WWTPs is relatively good, minimising the emission which is split between surface water and soil. The effectiveness of the WWTPs to irreversibly destroy the named non-fluorinated substances, increases the importance of live incidents – where there is a direct release without treatment.

For the PFAS-based substances there is a similar process with the majority of retained fire-water run-off from training sent for treatment at WWTPs. However, the efficacy is expected to be poor, with WWTPs ineffective at treating PFAS, meaning direct release to surface water / soil depending on the partition coefficient. Waste is thus the most important life-cycle stage for the PFAS substances (shown in Table B.6).

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A further consideration within the results is the magnitude of emissions to different environmental compartments. Review of the data highlights a further two key points.

Firstly, the PFAS-based surfactants are effective at low concentrations within the fire-fighting concentrate (≤3% w/w based on data from the stakeholder engagement), while the hydrocarbon/detergent alternatives are potentially less effective, meaning greater concentrations are needed within the concentrate product (aggregate of all substances within a given product equates to 10-20% w/w). Secondly, for the non-fluorinated alternatives a combination of substances is needed together to be effective.

Based on the market analysis and stakeholder engagement, a small set of substances are used across multiple different manufacturers. This means that while the non-fluorinated fire-fighting foams make up approximately one third of the market, the volumes of alternative surfactants can be greater than their PFAS counterparts because of the greater concentration needed. By way of example taking uncertainty into account the emissions of alkylamidobetaine (CAS 61789-40-0) are estimated as 9.5 tonnes to water and 8 tonnes to soil annually for the European Union. This is based on an assumed annual sale of 86 tonnes (within different products).

~~As means of comparison,~~With regards to the PFAS surfactants:

1-Propanaminium,N-(carboxymethyl)-N,N-dimethyl-3-[[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)sulfonyl]amino]-,inner salt (CAS 34455-29-3) has annual sales of 21.5 tonnes (within different products) and estimated emissions to water of 3.3 tonnes and to soil of 1.8 tonnes annually across the EU, i.e. an annual emissions in the environment of 26% compared to annual sales of this surfactant for use in firefighting foams.

The same number is obtained with the other PFAS surfactant used in the model (1-Propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-N-[[[(gamma-omega-perfluoro-C6-C16-alkyl)thio]acetyl] derives., inner salts (CAS 80475-32-7).

This number of 26% of annual emissions of PFAS in the environment compared to annual sales for use in firefighting foams is used in this assessment to calculate the total amount of PFAS emissions.

Considering an average annual use of 18,000 tonnes of PFAS-based fire-fighting foams and an average concentration of fluorosurfactants of 2.5%, **an annual emission of 117 tonnes of PFAS in the environment is calculated.** The table below summarises the results of the emissions calculations with different assumptions.

Table E.9 **Estimate of total PFAS emissions from fire-fighting foams**

	Tonnes of foams used per year	Concentration of PFAS surfactants in foams	Share of PFAS surfactants released into the environment	Tonnes of PFAS released
Low	14,000 t	2%	13%	36 t
Best	18,000 t	2.50%	26%	117 t
High	20,000 t	3%	39%	234 t

Sources: Annex A and Annex B (Section B.9.)

Commented [MD52]: This number will have to be recalculated based on the new data expected from Eurofeu (especially the annual usage rate per sectors and amount of stock). However, the logic of the emission model would remain the same.
@ [redacted] can you look at this model if you think it is correct and sufficient for the purpose of the restriction? (actually two related models: (1) "business as usual" scenario, i.e. without restriction and (2) restriction with different sub-scenarios and different transitional periods per type of use.

Commented [MD53]: Figures to be updated.

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This reflects potentially higher emissions of the non-fluorinated alternatives, primarily due to greater concentrations within the product itself. However, it is important to recognise that emission alone is not an indicator of impact, and the degradation rates, potential for bioaccumulation, and harmful effects also need to be considered. The next sub-section provides a consideration of the hazards for non-fluorinated alternatives, before the final sub-section in this chapter combines the emission estimates with hazard data to consider potential risks from exposure via uptake / man-via-the environment pathways.

[The Excel sheet with the underlying calculations for the selected PFAS substances and alternatives is available here:](#)



Emission%20scenario%20spreadsheetFF

Field Code Changed

[The following Excel sheet describes the emissions of PFAS from fluorinated foams over time depending on the different transitional periods for each type of use:](#)

https://activity.echa.europa.eu/sites/act-3/process-3-5/01%20Dossier%20preparation/36%20PFAS%20-%20Firefighting%20foams/03.%20Project%20management/Additional_consultancy_work/S_C3_emissions_and_costs_over_time/Calc_emission_20210311.xlsx

RMO 1

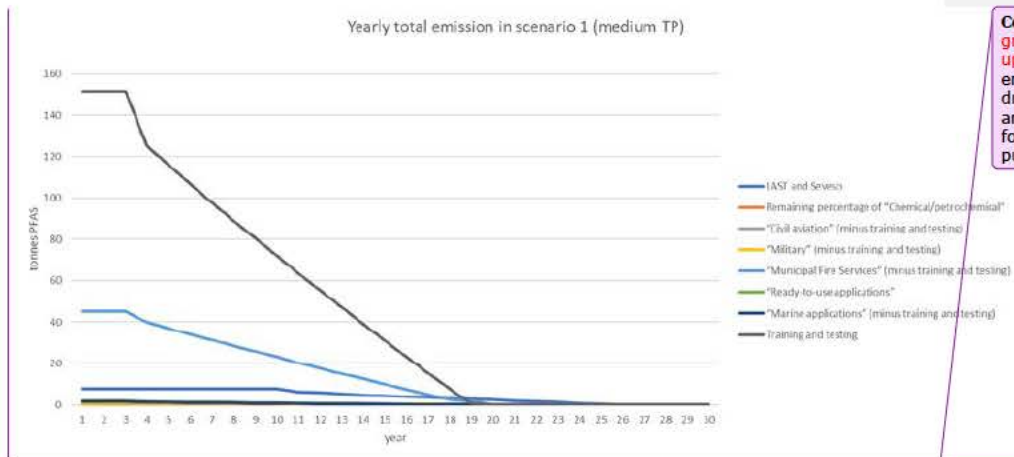
Under RMO 1, during the transition period a BAU scenario is assumed with constant stock, use and emissions, resulting in a flat emission line. After the transition period, a decrease in use and stock is assumed.

In the first year after the transition period, emissions decrease because:

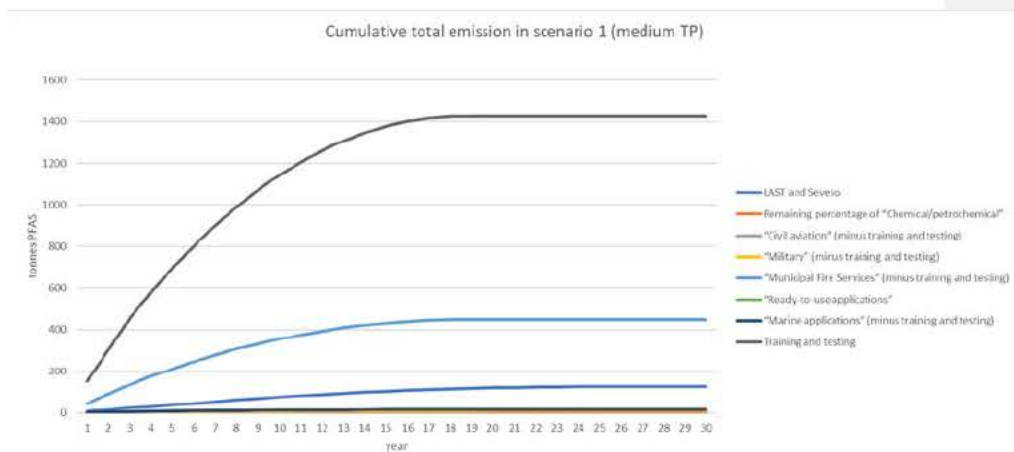
- 1) the formulation stops,
- 2) the stock decreases and consequently the leakage of the stock decreases, and
- 3) the use decreases and consequently, the emissions from the use of the foams also decrease.

In the following years, stock and use will continue to decrease, resulting in linearly decreasing emissions. The stronger decrease during the first year after the transition period is caused by the formulation stop.

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Commented [MD54]: Please be aware that these graphical representations will change significantly once updated input parameters are introduced (e.g. the emissions from "training" are expected to be drastically lower if the statements from Eurofeu/FFFC are supported by the foam users – i.e. that PFAS foams have been largely substituted for training purposes).



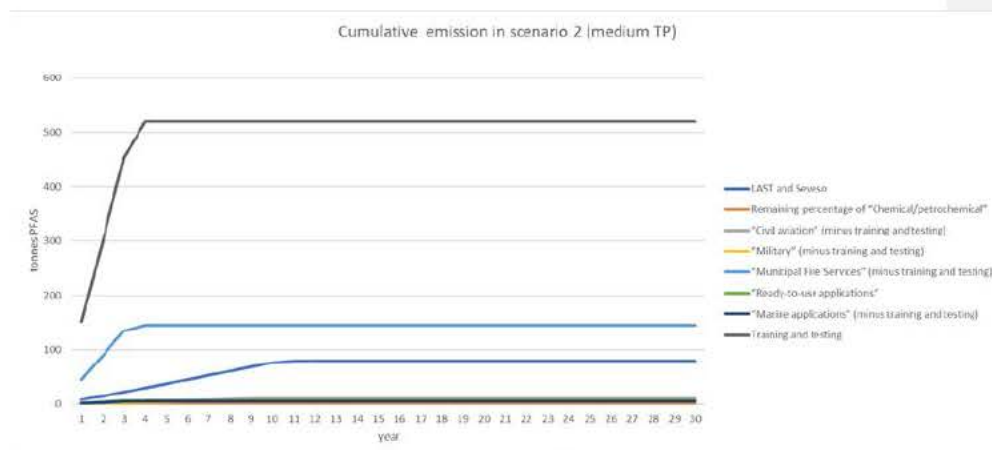
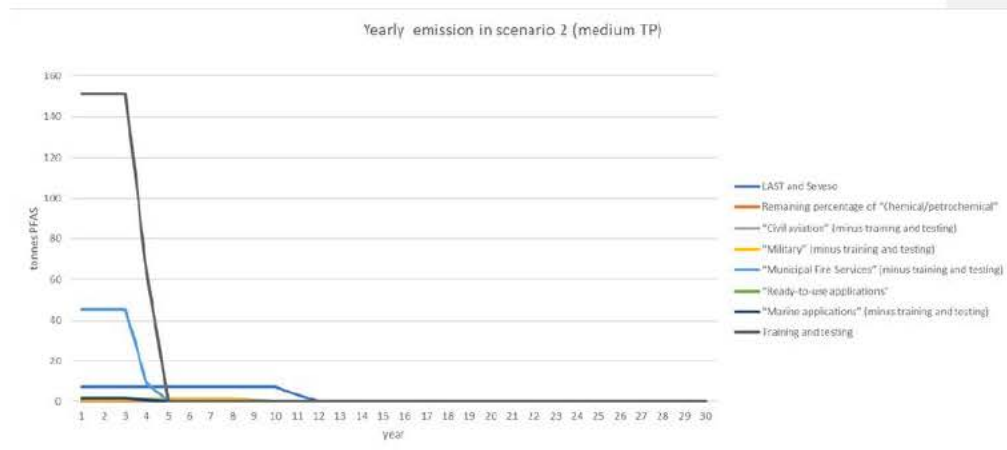
RMO 2

In RMO 2 a business as usual scenario with constant stock, use and emissions during the transition period is assumed, this results in a flat emission line.

In the first year after the transition period, the stock will be incinerated, all other emission sources due to formulation, use, leakage and expiration of stock will stop. This results in a lower emission than during the transition period because it is assumed that only 1% will be emitted to air during incineration.

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In the second year after the transition period, there will be no more emissions.



B.9.4. Other sources (for example natural sources, unintentional releases)

Not in scope.

B.9.5. Overall environmental exposure assessment

As Section B.9.3.

B.9.6. Combined human exposure assessment

B.9.6.1. Further considerations for exposure via uptake from food

This final sub-section considers the outputs of the emission model (See B.9.3) to identify the potential human exposure via uptake from food. This section is intended to provide a high-level review. Further work would be needed to assess the risks associated with specific sites or food production pathways, this has not been undertaken here.

The output of the emission model highlighted that, because the major use of fire-fighting foams is dominated by training, the efficacy of bunding/control measures is critical in preventing direct release to the environment. Secondly, the capacity of waste water treatment plants to successfully remove and/or destroy substances and prevent emission to environment is key to limiting their release to the wider environment.

The review of hazards highlighted that the fluorinated compounds have very low biodegradability and, in at least one case, very low PNEC values for soil. Furthermore, based on feedback from the workshop, the efficacy of waste water treatment plants against fluorinated compounds is typically poor. This suggests that the first major conclusion that can be drawn is that the PFAS-based compounds represent a greater risk to uptake and exposure than the non-fluorinated alternatives.

Further review of the non-fluorinated alternatives highlighted a number of compounds (see Table B.8) that also have very low PNEC values for water and soil (albeit higher than their fluorinated counterparts). The emission model also highlighted that the efficacy of the non-fluorinated substances as surfactants is typically poorer than fluorinated substances and thus greater concentrations are needed within the fire-fighting foam concentrate. This means that the potential emissions are higher, particularly where the same substance is used in multiple products by different manufacturers (i.e. in aggregate).

One further important consideration therefore could be in cases where fire-fighting foams are used multiple times at the same location. The emission model suggests that the majority of use would be for training. For those substances with particularly low soil PNECs and lower biodegradation properties a concern could be that, if the control measures are less effective in some locations, releases could repeatedly 'shock' soil microflora and fauna (i.e. the release has toxic effects upon the soil, with secondary or repeated releases before the microflora and fauna communities have a chance to recover). The removal of such biological degradation pathways from the soil could also have knock-on consequences for the biodegradation of the substance itself, meaning that persistence may be greater than the values quoted within Table B.8.

Based on consideration of these factors and in examination of the emission model alkylamidobetaine (CAS 61789-40-0) could be one such substance that meets these criteria, i.e. use concentrations (based on review of available SDS) are up to 10% w/w of the concentrate. It is used in at least four products by different manufacturers suggesting in use quantities could be significant. It also has PNEC values for fresh water of 0.0032 mg/l and soil of 0.0419 mg/kg dw (which can be considered low). In instances of sites with repeated use for training and less well-established control measures, effects for soil could highlight a need for further investigation.

Commented [MD55]: Add info on the claims that non-fluorinated substances have high BOD and therefore can lead to quick death of several aquatic species due to low oxygen left in water.

B.10. Risk characterisation

Tbc

Commented [MD56]: A detailed risk assessment will not be performed since the PBT approach will be taken, assessing mainly the emissions in the environment.

Commented [PJ57R56]: A detailed QUANTITATIVE ra not performed but a qualitative one yes. Can be adjusted from PFHxA rest or, if available, universal PFAS work.

Annex C: Justification for action on a Union-wide basis

See Section 1.2.

Annex D: Baseline

See Section 1.3.

Annex E: Impact Assessment

E.1. Risk Management Options

E.1.1. Proposed option(s) for restriction

Two main regulatory management options (RMOs) were considered:

- 1) Restriction (ban) on the **placing on the market** of PFAS-based fire-fighting foams (hereafter referred to as **RMO 1**). The use of legacy foams, i.e. foams already in stock at producers' or users' sites, is still permitted; and
- 2) Restriction (ban) on the **placing on the market and the use** of PFAS-based fire-fighting foams (hereafter referred to as **RMO 2**). The legacy foams, i.e. foams already in stock at producers' or users' sites, should be disposed of safely.
- 3) Restriction (ban) on the manufacture, placing on the market and the use of PFAS-based fire-fighting foams (hereafter referred to as **RMO 1**)
- 2)4) Other RMOs

Commented [MD58]: To be developped

E.1.2. Discarded restriction options

Not applicable.

E.1.3. Other Union-wide risk management options than restriction

See Section 2.7.4.

E.2. Alternatives

E.2.1. Description of the use and function of the restricted substance(s)

PFAS-based fire-fighting foams find application in a broad range of sectors, such as aviation, marine, oil and gas, offshore oil, refineries, chemicals and railways¹³⁰.

The main function of the PFAS contained in the foam is to act as a surfactant, i.e. to form a film over the burning liquid surface in order to prevent flammable gases from being released from it. This is a particularly relevant feature that enables applications in industrial fires - for example tank fires, where large quantities of flammable liquid are stored. They are used for training purposes and in a variety of fire incidents, from small fires to the above-mentioned large tank fires, and can be applied both with mobile and ~~semi~~-stationary equipment.

¹³⁰ A respondent responsible for railway maintenance stated that PFAS-based foams are used in railways; the use of fire-fighting foams is particularly relevant for fire-protection in railway tunnels. The reason is that railways can carry various chemicals and other dangerous goods and, if they catch fire in tunnels, it is particularly critical and fires can be much more difficult to extinguish.

E.2.2. Identification of potential alternative substances and techniques fulfilling the function

A list of the most common alternative fluorine-free products that are widely used in the EU has been generated. These provide a starting point which can be compared to the risk, performance and cost of PFAS-based products.

Alternative techniques could be changes in demand for flammable fuels which would reduce the need for AFFFs. Application of e.g. electric aircraft and phase out of hydrocarbon fuels for vehicles would reduce the needs for AFFFs, but are by the authors of this report not considered feasible alternative solutions in the short term.

The selection of fluorine-free products for further analysis has been based on the following criteria:

- **Use** – The use of the products has been reported by several stakeholders, ensuring that the products analysed are commonly used in the EU as alternatives for PFAS-containing foams;
- **Chemical group** – The products represent different chemical groups according to the grouping in the substance identification, i.e. hydrocarbons, detergents, siloxanes and proteins. Some products may contain a combination of substances from these groups;
- **Technical feasibility** – The products do actually represent alternatives/replacements for PFAS- containing foams, including in critical situations (with large fires). Technical feasibility also considers the combination of the foam concentrate, the application system and the application rate to establish whether the alternative is a viable replacement. Case studies of critical applications serve as a starting point for successful replacement of PFAS-containing foams with fluorine-free alternatives. Training foams have been excluded as they are already available and widely used for all applications. ;
- **Manufacturers** – The products originate from different manufacturers;
- **Availability** – The products are known to be on the market in the EU and are available without further R&D delays or costs; and
- **Complementarity** – The products cover jointly all major applications of PFAS-containing foams and can be used in different conditions.

An initial shortlist with 30 products from 8 manufacturers was presented at the workshop undertaken as part of the underlying study (see Annex G for more details on the workshop), and participants were asked which were the most commonly used and viable. On the basis of the workshop feedback, further review by the study team and responses from stakeholders, a list of products for further analysis was generated. This is shown in Table E.1 along with a justification of why these specific products have been chosen.

For each of the manufacturers, one or two products in the product range has been selected for the more detailed assessment. The selection has been based on the available information on the feasibility of using the alternatives with particular emphasis on products demonstrated as viable alternatives to PFAS-containing foams in airports and the petrochemical sector. The information provided in Table E.1 is supplemented with two representative case studies in Section E.2.4.

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The remaining products on the shortlist presented at the workshop were from the manufacturers Auxquimia (EE-3 Newtonian Training foam, and Unipol-FF), Fomtec (the Enviro product range) and the 3F Company (Freedol SF). None of the companies have answered the questionnaire and only limited information on the feasibility has been obtained from the stakeholder consultation. These products were not included in the list, but this does not indicate that these products are considered less efficient alternatives to the PFAS-based foams, merely that less information on the feasibility of using these foams was available for the assessment. Seven substances have been selected in order to strike a balance between ensuring variety in coverage of alternatives and depth of analysis that is possible.

It is important to note that during the substance identification, a group of potential alternative fluorine-free products, the **siloxane-based** alternatives, were identified. These have not been identified as being widely used and, furthermore, at the stakeholder workshop, **concerns were raised by governmental stakeholders in relation to PBT and/or vBvP properties of some siloxanes**. They have therefore not been selected from the more detailed analysis.

One **protein-based** product, PROFOAM 806G from the company Gepro has been mentioned to be in use during the stakeholder consultation. However, specific data on users, application or feasibility have not been provided by the stakeholder consultation and the manufacturer and products cannot be identified. Protein-based foams are marketed by Profoam srl (PROVEX AR 6-6), Angus PFAS based foams (TF 3 and TF90 for training purposes) and ■ Stahmer (Foamousse® product range). No information on these products has been provided for the stakeholder consultation but one product from the Foamousse® product range has subsequently been added to the example list in the table below.

Table E.1 Shortlist of fluorine-free alternative products for assessment

Product name	Manufacturer	Chemical group(s)	Current use sector of the product where PFAS-based products are currently used	Reason for shortlisting	Other marketed fluorine- free products from the manufacturer for hydrocarbon fires
Respondol ATF 3-6%	Angus fire	Hydrocarbons and detergents	Petrochemicals -processing, storage and transport of hydrocarbons and polar solvents	Applicable for all types of flammable liquid fires	JetFoam ICAO-C (aviation) JetFoam ICAO-b (aviation) Syndura (aviation, forestry)
Re-Healing Foam RF1 1%	Solberg	Hydrocarbons and detergents	Petrochemicals - offshore oil installations and onshore terminals and refineries	Widely used - detailed information on the feasibility of using the substances as alternatives for PFAS-	8 other products in the Re-Healing Foam RF product range

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Product name	Manufacturer	Chemical group(s)	Current use sector of the product where PFAS-based products are currently used	Reason for shortlisting	Other marketed fluorine- free products from the manufacturer for hydrocarbon fires
				based products in the petrochemical sector provided in Case 2	
Re-Healing Foam RF3x6 ATC	Solberg	Hydrocarbons and detergents	Aviation	Widely used - detailed information on the feasibility of using the substances as alternatives for PFAS-based products in the aviation sector provided in Case 1	
Moussol FF 3x6	■■■■■	Hydrocarbons and detergents	Aviation Petrochemicals	Widely used in several major EU airports	A number of products in the Sthamex® product range (municipal fire services, aviation, training foams)
Foammousse 3% F-14	■■■■■	Protein	According to manufacturer: Petroleum industry and on oil tankers	Best available example of protein-based products	Training foam N (training) vaPUREx® LV 1% F10 (extensive fires of non-polar liquids) vaPUREx® LV ICAO B 3% F-10 (aviation)
Ecopol Premium	Bioex	Hydrocarbons and detergents	Aviation	Mentioned by manufacturer and other stakeholders, as applicable	BIO FOR

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Product name	Manufacturer	Chemical group(s)	Current use sector of the product where PFAS-based products are currently used	Reason for shortlisting	Other marketed fluorine- free products from the manufacturer for hydrocarbon fires
				for hydrocarbon fires, all types of flammable polar solvent liquids and applicable for tank fire fighting	BIO FOAM 5 and 15 (storage facilities, marine) BIO T3 and BIO T6 (training foams) Ecopol F3 HC, Ecopol A
Orchidex BlueFoam 3x3	Orchidee	Hydrocarbons and detergents	Aviation	Has according to stakeholder response substituted for AFFF for one of the biggest airports in Germany	Other products in the Orchidex Bluefoam product range

E.2.3. Risk reduction, technical and economic feasibility, and availability of alternatives

Additional information on the technical and economic feasibility and availability of shortlisted products has been collected through both the earlier literature review step and further follow-up with stakeholders. The properties of the shortlisted products are listed in the following tables and are further used in the impact assessment in subsequent sections.

The full chemicals composition of the products is in general not available. The following tables indicate the substances listed in the safety data sheets i.e. the constituents classified as hazardous. It should be noted that not all human health or environmental hazard endpoints (e.g. endocrine disrupting effects) have necessarily been assessed in detail for each component by the foam manufacturers. Therefore, it should be kept in mind that the conclusion on risks in the tables below are based on the information provided in the product safety data sheets and hence other hazards may become evident in the future. A comprehensive list of identified substances in alternatives is provided in Section B.1.

Table E.2 Assessment of Respondol ATF 3-6%

Product name	Respondol ATF 3-6%
Manufacturer	Anqus Fire
Chemical group	Hydrocarbons and detergents.

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Product name		Respondol ATF 3-6%
Chemical composition		Substances listed in safety data sheet: 1-dodecanol 1-tetradecanol propylene glycol monobutyl ether disodium isodecyl sulfosuccinate sulfuric acid, mono-C8-10-alkyl esters, sodium salts reaction mass of C-isodecyl and C-isodecyl sulphonatosuccinate.
Proposed PFAS foam substitution (as specified by manufacturer)		Replacing traditional AFFF and FFFP foam concentrates as well as fluoroprotein foam.
Technical feasibility	Applications areas (as specified in technical specification)	Class B hydrocarbon fuels at 3% and polar solvent fuels at 6%. Class A fuels (as wetting agent). Used in high risk situations where hydrocarbons (such as oils, gasoline, diesel fuel, and aviation kerosene) are stored, processed, or transported and/or polar solvents (such as alcohols, ketones, esters, and ethers) are stored, processed, or transported.
	Compliance with international performance standards	EN 1568 Part 3 and 4; Highest approval rating on all fuels using all waters; 1A/1A – 1A/1A – 1A/1A. (see Appendix 5 of the underlying study ¹³¹)
	Examples of use experience and performance compared to PFAS-containing foams	Used within the petroleum industry. No further details available. Marketed for use in Power and Industry (other than petrochemical), municipal fire brigades and forestry
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	The product is not intended for the aviation sector for which the manufacturer markets other products (JetFoam and Syndura product ranges) The corresponding 3-3% product has passed Lastfire test in fresh water and sea water. Stakeholders have indicated that fires in very large tanks are still challenging
	Need for changes in equipment	In general no need for replacement of equipment, but adjustment and in some case change of components
Economic feasibility:	Unit price	No data
	Unit price as compared with PFAS-containing foam for same application	No data
	Relative volume required to achieve comparable/best possible performance	No data
	Storage, shelf-life	Max. continuous storage temperature 49 C° (no performance loss after thawing), min. 10 years.
	Frequency of foam replacement	Depending on application and difficult to compare with the PFAS-containing. Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	No data
	Production capacity in the EU	No data
Risks:	CMR properties	Substances in the product do not meet the CMR criteria
	Other potential human health concern	Hazard classification of some constituents: H315 - Causes skin irritation.

¹³¹ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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Product name		Respondol ATF 3-6%
		H319 - Causes serious eye irritation. H302 - Harmful if swallowed No other health concern identified
	PBT or vPvB properties	The product does not meet the PBT or vPvB criteria.
	Other environmental risk concern	Hazard classification of some constituents: -dodecanol (EC No 203-982-0; CAS No 112-53-8): H400 - Very toxic to aquatic life -tetradecanol (EC No 204-000-3; CAS No 112-72-1): H410 - Very toxic to aquatic life with long-lasting effects -dodecanol (EC No 203-982-0; CAS No 112-53-8): H411 - Toxic to aquatic life with long-lasting effects Sodium laureth sulphate (EC No 500-234-8; CAS No 68891-38-3): H412 - Harmful to aquatic life with long lasting effects
	GreenScreen® level	Level bronze ^[1] . Level Bronze Screening Requirements are ^[2] 1. Each intentionally added chemical compound present above 0% by weight (>0 ppm) and each impurity present at or above 0.01% by weight (100 ppm) in the product is screened with GreenScreen® List Translator™. 2. Each screened chemical compound in the Product Inventory has a GreenScreen® List Translator™ score of LT-P1, LT-UNK, and/or NoGSLT. No LT-1 scores are permitted in certified products. 3. Product-level acute aquatic toxicity testing results in LC50 and/or EC50 values >10 mg/l for each of the following groups of organisms: fish, aquatic and invertebrates, and algae.
	Conclusion on risks	As the substances are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products. Some constituents are classified toxic or very toxic to aquatic life, for one constituent with long-lasting effects.

References:

[1] <https://www.greenscreenchemicals.org/certified/products>

[2]

https://www.greenscreenchemicals.org/images/ee_images/uploads/resources/GSCFirefightingFoamStandardV1.0_FINAL.pdf?cachebuster:38

Table E.3 Assessment of Re-Healing Foam RF3x6 ATC

Product name		Re-Healing Foam RF3x6 ATC
Manufacturer		Solberg
Chemical group		Hydrocarbons and detergents
Chemical composition		Substances listed in safety data sheet 2-(2-butoxyethoxy)ethanol starch sucrose 1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acylderivs., hydroxides, innersalts
Proposed PFAS foam substitution (as specified by manufacturer)		Replacing traditional AFFF and FFFP foam concentrates as well as fluoroprotein foams
Technical feasibility	Applications areas (as specified in technical specification)	Class B hydrocarbon fuels at 3% and polar solvent fuels at 6% Class A fuels
	Equipment	Aspirating or non-aspirating devices

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Product name		Re-Healing Foam RF3x6 ATC
	Compliance with international performance standards	EN 1568 Part 3 and 4; levels not indicated ICAO Levels B and C (see Appendix 5 of the underlying study ¹³²)
	Examples of use experience and performance compared to PFAS-containing foams	Airport Fire Service, both airport rescue firefighting and training. Examples: Used at Copenhagen Airport. Fulfilling the need of an alcohol resistant foam. Also used by the Melbourne Metropolitan Fire Brigade (MFB) on class B fires; Based on MFB's experience, Solberg RF3x6 foam concentrate performs just as well as the previously used fluorinated AFFF concentrate (IPEN 2019).
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	None identified within aviation. Several stakeholders indicate that the performance standards required by the ICAO were developed for PFAS-based foams, are outdated and/or are not covering the multiple applications within the aviation sector. For this reason(s), several airports conducted internal testing schemes before implementation of PFAS-free foams.
	Need for changes in equipment	No identified. In the case of Copenhagen Airport, the investment in fire trucks was not strictly conditioned by the foam replacement, but the coincident introduction of new trucks and foam was seen as a cumulative benefit.
Economic feasibility:	Unit price	Appr. €5/l
	Unit price as compared with PFAS-containing foam for same application	Range from similar to +20%.
	Relative volume required to achieve comparable/best possible performance	No difference or differences/larger volumes depending on application. In certain applications, a 6% foam (ICAO Level C) has been found to work better than a 3% mixture (ICAO Level B).
	Storage, shelf-life	1.7 to 49 °C* (no quality loss after thawing), 20 years
	Frequency of foam replacement	Depending on application. Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	Produced in Norway and Spain
	Production capacity in the EU	No data
Risks:	CMR properties	Substances in the product do not meet the CMR criteria
	Other potential human health concern	Hazard classification of one constituent: H319 - Causes serious eye irritation.
	PBT or vPvB properties	According to SDS, due to insufficient data no statement can be made whether the components fulfil the criteria of PBT (vPvB criteria not addressed)
	Other environmental risk concern	Hazard classification of one constituent: 1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acylderivs, hydroxides, innersalts (EC No 268-761-3; CAS No 68139-30-0);

¹³² Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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Product name	Re-Healing Foam RF3x6 ATC
	H411 - Toxic to aquatic life with long-lasting effects
Conclusion on risks	Substances in the product do not meet the CMR criteria. No statement can be made on whether the components fulfil the PBT criteria. One constituent is toxic to aquatic life with long-lasting effects.

Table E.4 Assessment of Re-Healing Foam RF1 1%

Product name	Re-Healing Foam RF1 1%
Manufacturer	Solberg
Chemical group	Hydrocarbons and detergents
Chemical composition (according to SDS)	Substances listed in safety data sheet: d-glucopyranose, oligomers, decyl octyl glycosides sodium octyl sulphate sodium decyl sulphate alpha-sulfo-omega-hydroxy-poly(oxy-1,2-ethanediyl), C9-11 alkyl ethers, sodium salts 1-propanaminium, N-(3-aminopropyl)-2-hydroxy-N,N-dimethyl-3-sulfo-, N-coco acyl derivs., hydroxides, inner salt amides, coco, N-[3-(dimethylamino)propyl] 1-propanaminium, 3-amino-N-(carboxymethyl)-N,N-dimethyl-,N-coco acyl derivs., hydroxides, inner salts amides, coco, N-[3-(dimethylamino)propyl], N-oxides sucrose 2-(2-butoxyethoxy)ethanolsulfuric acid, mono-C12-14-alkyl esters, compound with triethanolamin
Proposed PFAS foam substitution (as specified by manufacturer)	Replacing traditional AFFF and FFFP foam concentrates as well as fluoroprotein foams
Technical feasibility	Applications areas (as specified in technical specification)
	Petrochemicals sector - offshore oil installations and onshore terminals and refineries Class B hydrocarbon fuels (not intended for polar solvent fuels) Class A fuels
	Compliance with international performance standards
	EN 1568 Part 3 (see Appendix 5 of the underlying study ¹³³)
Technical feasibility	Examples of use experience and performance compared to PFAS-containing foams
	Used at offshore facilities in Norway. Partially implemented at onshore facilities as well
Technical feasibility	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why
	According to data sheet, the product is not intended for use on Class B polar solvents fuels. Diverging opinions among stakeholders: Specific applications related to large storage tanks in the petroleum industry (e.g. terminals and oil refineries) may require PFAS-based foams. However, the use of PFAS-free foams has also been assessed as safe for sub-ground large storage tanks. One stakeholder noted that testing and qualification of non-PFAS foams and obtaining the necessary military approvals for use in all vessels / fire-fighting systems will take many years, and the associated costs will be very high.

¹³³ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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Product name		Re-Healing Foam RF1 1%
	Need for changes in equipment	The experience with the case from the Norwegian offshore sector (Equinor, case 2) is that at a few facilities, adjustment of equipment was necessary, but usually, the same equipment was used and additional costs for new equipment were not necessary. Furthermore, substitution was done in relation to scheduled maintenance stops, turnarounds or during upgrades, thus not imposing further additional costs to the company.
Economic feasibility:	Unit price	Approx. €5.0-5.5/l
	Unit price as compared with PFAS-containing foam for same application	Case 2 indicates approx. 30% more expensive than PFAS products
	Relative volume required to achieve comparable/best possible performance	Same volumes, no difference to PFAS foams
	Storage, shelf-life	-10 to 50 C° (no quality loss after thawing), 20 years
	Frequency of foam replacement	Depending on application. Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	Available in EU (tonnage not known)
	Production capacity in the EU	Manufactured in the EU: no data Sold in the EU: no data Used in the EU: no data
Risks:	CMR properties	Substances in the product do not meet the CMR criteria
	Other potential human health concern	Hazard classification of product: H315 - Causes skin irritation H318 - Causes serious eye damage. Hazard classification of some constituents: H302 - Harmful if swallowed H314 - Causes severe skin burns and eye damage
	PBT of vPvB properties	According to SDS, due to insufficient data no statement can be made whether the components fulfil the criteria of PBT and vPvB
	Other environmental risk concern	Hazard classification of one constituent: amides, coco, N-[3-(dimethylamino)propyl] (-) (EC No 268-771-8; CAS No 68140-01-2); OH400: Very toxic to aquatic life
	Conclusion on risks	he constituents of the product do not meet the CMR criteria. Due to insufficient data no statement can be made on whether the constituents fulfil the PBT and vPvB criteria. One constituent is very toxic to aquatic life.

Table E.5 Assessment of Moussol FF 3x6 (F-15)

Product name		Moussol FF 3x6 (F-15)
Manufacturer		
Chemical group		Hydrocarbons and detergents
Chemical composition		Substances listed in safety data sheet 1,2-ethandiol 2-(2-butoxyethoxy)ethanol triethanolammonium-laurylsulfate alkylamidobetaine

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Product name		Moussol FF 3x6 (F-15)
Proposed PFAS foam substitution (as specified by manufacturer)		Replacing alcohol-resistant AFFF.
Technical feasibility	Applications areas (as specified in technical specification)	Polar (water-miscible) and non-polar hydrocarbons as well as mixtures of the two (class A and B fires). Can be used as a low, medium and high expansion foam.
	Compliance with international performance standards	DIN EN 1568: Part 3 (Heptane): IIIB/IIID, Part 1: Medium ex. - Part 2: High ex. ICAO Low expansion foam - Level B DIN EN 3 21A (see Appendix 5 of the underlying study ¹³⁴)
	Examples of use experience and performance compared to PFAS-containing foams	Used within aviation, for example in Sweden, by Swedavia, and in the UK at Heathrow Airport. Swedavia is a state-owned company that owns, operates and develops Sweden's national basic infrastructure of airports. The product is used at all Swedish airports as well as for all aircraft applications at Heathrow airport including training. 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.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	One stakeholder states that the foam must be used aspirated, which reduces throw length. This may result in accessibility problems, for examples for large tanks. Other critical applications may be tank pit scenarios and large puddle fires (>400 m ²).
	Need for changes in equipment	No data
Economic feasibility:	Unit price	No data
	Unit price as compared with PFAS-containing foam for same application	Product costs about half of the corresponding PFAS-based foam, but approx. double volume is needed, thus the costs are the same. More storage capacity is required though.
	Relative volume required to achieve comparable/best possible performance	Depending on application.
	Storage, shelf-life	-5 to 50°C (without quality loss below the specified frost resistance limit) Shelf life of > 10 years, if stored according to recommendations
	Frequency of foam replacement	10 years
Availability:	Volume manufactured, sold and used in the EU	Produced in Germany, data on volume considered confidential by manufacturer
	Production capacity in the EU	No data
Risks:	CMR properties	Substances not classified with CMR properties
	Other potential human health concern	Hazard classification of product: H319 - Causes serious eye irritation. Hazard classification of one constituent: H302 - Harmful if swallowed H319 - Causes serious eye irritation. H373 - May cause damage to kidneys through prolonged or repeated exposure if swallowed.
	PBT of vPvB properties	Substances in the product do not meet the PBT/vPvB criteria

¹³⁴ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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Product name		Moussol FF 3x6 (F-15)
	Other environmental risk concern	Hazard classification of one constituent: Triethanolammonium laurylsulfate (EC No 288-134-8; CAS No 85665-45-8): 412: Harmful to aquatic life with long-lasting effects C
	Conclusion on risks	As the constituents are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products. One constituent is classified harmful to aquatic life with long-lasting effects.

Table E.6 Assessment of FOAMOUSSE® 3% F-15

Product name		FOAMOUSSE® 3% F-15
Manufacturer		
Chemical group		Protein
Chemical composition		Is a low expansion protein foaming agent based on natural re-growing protein carriers, foam stabilisers and antifreezing compounds. Substances listed in safety data sheet: iron-(ii)-sulfate-7-hydrate ammoniumchloride
Proposed PFAS foam substitution (as specified by manufacturer)		Not specified
Technical feasibility	Applications areas	Typically used in non-polar hydrocarbon fires in the petroleum industry and on oil tankers In particular used in the marine sector. Has the advantage that the product is compatible with black steel and does not require equipment made from stainless steel or plastics (same for other protein-based products). Has been in use for many years and not developed as an alternative to the PFAS-containing foams. Designed for the use with all mobile and stationary low expansion foam equipment and systems for fighting fires of class A + B.
	Compliance with international performance standards	EN 1568 part 3 (heptane)
	Examples of use experience and performance compared to PFAS-containing foams	Mainly used in the marine sector
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	Only applicable for smaller fires and not applicable for e.g. the aviation sector and other sectors with higher requirements.
	Need for changes in equipment	No data
Economic feasibility:	Unit price	Not specified but the price is indicated as relatively low
	Unit price as compared with PFAS-containing foam for same application	Lower
	Relative volume required to achieve comparable/best possible performance	No data
	Storage, shelf-life	A shelf life of >10 years, if stored according to the manufacturer's recommendations
	Frequency of foam replacement	No data

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Product name		FOAMOUSSE® 3% F-15
Availability:	Volume manufactured, sold and used in the EU	Produced in Germany, data on volume considered confidential by manufacturer
	Production capacity in the EU	No data
Risks:	CMR properties	Substances in the product do not meet the PBT/vPvB criteria
	Other potential human health concern	Hazard classification of some constituents: H302 - Harmful if swallowed H315 - Causes skin irritation H319 - Causes serious eye irritation
	PBT of vPvB properties	Substances do not meet the PBT/vPvB criteria of REACH
	Other environmental risk concern	None of the constituents have hazard classification for environmental effects N
Conclusion on risks		As the constituents are not classified with CMR properties and do not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products. The product is particularly applied in the marine sector, where volumes used for training are discharged directly to the sea. None of the constituents have hazard classification for environmental effects.

Table E.7 Assessment of Ecopol Premium

Product name		Ecopol Premium
Manufacturer		BIOex SAS
Chemical group		Hydrocarbons and detergents
Chemical composition		Substances listed in safety data sheet 2-(2-butoxyethoxy)ethanol Ethandiol Alkyl Sulfate Sodium octyl sulphate
Proposed PFAS foam substitution (as specified by manufacturer)		Equivalent to AFFF (certified 1A / 1A - EN 1568-3) and burn back resistance equal to fluoroprotein foams ECOPOL PREMIUM can substitute for FILMOPOL range from same company (other products from the company can substitute for other PFAS-based products)
Technical feasibility	Applications areas (as specified in technical specification)	Industrial fires: landfills, plastics, tyres, etc. Hydrocarbon fires: fuel, diesel oil, petrol, kerosene, etc. Polar solvent fires: alcohols, ketones, ethers, etc. Urban fires: waste bins, furniture, textiles, etc. Effective at Low, Medium and High Expansion
	Compliance with international performance standards	EN 1568 - 1: Conforms EN 1568 - 2: Conforms EN 1568 - 3: 1A / 1A (highest level) EN 1568 - 4: 1A / 1A (highest level) Oil industry: LASTFIRE Forest fire standards: CEREN Certificate Certification in progress : UL 162 / GESIP (see Appendix 5 of the underlying study ¹³⁵)

¹³⁵ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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Product name		Ecopol Premium
	Examples of use experience and performance compared to PFAS-containing foams	According to producer's datasheet is used in the oil and chemical industry, pharmaceutical industry, aviation, marine, and fire and rescue service. Used in industrial uses for tank fire fighting. Further details not available.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	Diverging opinions among stakeholders. One stakeholder notes that the product is not technically feasible for large scale tank fire fighting, high-hazard industry manufacturing, oil tankers fire suppression systems, large spillage of flammable liquids
	Need for changes in equipment	One stakeholder indicated that re-building of firefighting or fire protection systems would be very costly, but no detailed information is provided.
Economic feasibility:	Unit price	3.5 EUR/l
	Unit price as compared with PFAS-containing foam for same application	Approximately the same effective price
	Relative volume required to achieve comparable/best possible performance	One stakeholder responds 30 – 50% more volume needed.
	Storage, shelf-life	-30°C to 60°C, 10 years warranty
	Frequency of foam replacement	Depending on application. Commonly, the foam is used continuously for training and system testing as well, thus not requiring replacement.
Availability:	Volume manufactured, sold and used in the EU	Production in EU: 700,000 l/year; Sale in EU: 500,000 l/year
	Production capacity in the EU	No data
Risks:	CMR properties	Substances not classified for CMR properties
	Other potential human health concern	Hazard classification of one constituent: H318 - Causes serious eye damage.
	PBT or vPvB properties	No PBT or vPvB properties identified
	Other environmental risk concern	None of the constituents are classified with regard the environmental hazards.
	GreenScreen® level	Level Bronze. Level Bronze Screening Requirements are 1. Each intentionally added chemical compound present above 0% by weight (>0 ppm) and each impurity present at or above 0.01% by weight (100 ppm) in the product is screened with GreenScreen® List Translator™. 2. Each screened chemical compound in the Product Inventory has a GreenScreen® List Translator™ score of LT-P1, LT-UNK, and/or NoGSLT. No LT-1 scores are permitted in certified products. 3. Product-level acute aquatic toxicity testing results in LC50 and/or EC50 values >10 mg/l for each of the following groups of organisms: fish, aquatic and invertebrates, and algae.
	Conclusion on risks	As the constituents are not classified with CMR properties and it does not meet the PBT/vPvB criteria, the overall risks are considered lower than the risks of PFAS-based products

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Table E.8 Assessment of Orchidex BlueFoam 3x3

Product name		Orchidex BlueFoam 3x3
Manufacturer		Orchidee
Chemical group		Hydrocarbons and detergents
Chemical composition		Substances listed in safety data sheet: L2-(2-butoxyethoxy)ethanol, diethylene glycol monobutyl ether ethanediol, ethylene glycol alcohols, C10-16,ethoxylated, sulfates, ammonium salts D-glucopyranose oligomeric C10-16-alkyl glycosides ammonium lauryl sulfate alcohols, C10-16,ethoxylated dodecanol -1
Proposed PFAS foam substitution (as specified by supplier)		Products can be seen as 1:1 replacement on Sthamex AFFF and Moussol Products or other AR or usual AFFF products. Appropriate foaming is needed – as for all PFAS-free products - which can usually be realised with the equipment to hand. On systems the nozzles/sprinklers needs changing. Main strength on non-polar liquids.
Technical feasibility	Applications areas (as specified by supplier)	Aviation, petrochemical sector For all uses till tanks > 15 m diameter.
	Compliance with international performance standards	EN 1568 - 3: 1B EN 1568 - 4: 1A / 2B Oil industry Lastfire (Heptane), ICAO Level B (see Appendix 5 of the underlying study ¹³⁶)
	Examples of use experience and performance compared to PFAS-containing foams	Indicated by supplier that one of the biggest airports in Germany has changed to the product. After tests with their trucks to test the capabilities for their dosing-system, the airport has decided to change all trucks to PFAS-free and has now started a project to change also all systems.
	Critical uses/applications where product do not meet (fully or partially) the required performance standard and why	Indicated by supplier that fires in substances like isopentane (with low boiling points of 28°C) are difficult and PFAS-containing foams may have an advantage. This could according to the supplier be overcome with a higher application-rate and/or more technical changes to technique and equipment. In the view of supplier and experience from dozens of tests done in the past 10 or more years it's generally possible to change 99.9 % of all current scenarios to PFAS-free.
	Need for changes in equipment	Indicated by supplier as normally none. Some information from airport in Germany that changes of trucks may be needed, but not indicated it this concerns adjustment or actual changes in equipment.
Economic feasibility:	Unit price	Depending on concentration, the price in sales is in the range €2.5 – 6.0/l
	Unit price as compared with PFAS-containing foam for same application	No data
	Relative volume required to achieve comparable/best possible performance	According to supplier, if there might be a gap, it's in between 5-10 % in the extinguishing-time for PFAS-containing products in regard to mainly unpolar and secondly polar liquids. In tests, nearly 1:1 results

¹³⁶ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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Product name		Orchidex BlueFoam 3x3
Availability:		were found, but this is strongly depending on the fuels and additives.
	Storage, shelf-life	No data
	Frequency of foam replacement	5-15 years
	Volume manufactured, sold and used in the EU	Stakeholder (not the manufacturer) estimates volume sold in the EU at 800 t/year
Risks:	Production capacity in the EU	No data
	CMR properties	Substances not classified with CMR properties
	Other potential human health concern	Hazard classification of several constituents: H302 - Harmful if swallowed H318 - Causes serious eye damage H319 - Causes serious eye irritation H315 - Causes skin irritation
	PBT of vPvB properties	Product has not been tested according to SDS
	Other environmental risk concern	Hazard classification of one constituent: Ammonium lauryl sulfate (EC No 218-793-9; CAS No 2235-54-3): H412 - Harmful to aquatic life with long lasting effects.
Conclusion on risks		None of the constituents are classified with CMR properties. Due to lack of information it cannot be concluded if the constituents fulfil the PBT and vPvB criteria. One constituent is harmful to aquatic life with long lasting effects.

E.2.4. Representative case studies where fluorine-free alternatives are already in use in the EU

An important issue in identifying the feasibility of alternatives is the consideration of the process that is involved in adopting the alternative, including systems that need to be changed and considerations such as additional training of users. Substitution examples from companies that are already using alternatives therefore act as a key starting point or proof of principle that a transition is (or is not) possible and the main costs and benefits from real world examples. In order to better understand the options and challenges of replacing PFAS-containing AFFFs, two cases where PFAS-containing AFFFs have been successfully replaced are described in more detail in the following case study examples.

E.2.4.1. Case 1 Aviation sector - Copenhagen Airport in Denmark¹³⁷

Foam used

In general, the majority of firefighting foam is used for testing and training at airports. Only a very small percentage is used operationally for emergency response at live events. At

¹³⁷ Case description is based on the following sources: IPEN position paper 2018 (https://ipen.org/sites/default/files/documents/IPEN_F3_Position_Paper_POPRC-14_12September2018d.pdf); IPEN position paper 2019 (https://ipen.org/sites/default/files/documents/the_global_pfes_problem-v1_5_final_18_april.pdf); Kim T. Olsen, 2017, Crashtender med skumkanoner (https://beros.dk/skum/Kim_Thorbjørn_Olsen_CPH.pdf); Personal communication with Kim T. Olsen, 2019

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Copenhagen airport, the same fluorine-free foam (Solberg Re-healing foam RF3x6 ATC fluorine-free foam) is used for training and emergency response.

Timeline in the shift from PFAS foams to fluorine free-foams

- In 2003, the airport recognised PFAS in the run-off firewater from the airport's training area and its burn pit. This resulted in restrictions on use of PFAS-containing AFFF and later, in 2006, all training with PFAS foams stopped;
- In 2008, testing with fluorine-free foams was started. Re-Healing foams from Solberg were identified as suitable alternatives; and
- In 2009, the airport conducted additional tests required by the ICAO ARRF working group. All tests (ICAO foam test and test according to the US Mil-Spec protocol, including the NFPA 403), were passed by the fluorine-free foam carrying airport crash tenders. The results from the UK CAA/ICAO tests also showed that CAFS (Compressed Air Foam System; application of foam with non-aspirating turret)¹³⁸ were about 40% more efficient in fire extinction compared to aspirated foams. CAFS with PFAS and PFAS-free foams were both shown to be efficient. The PFAS-free foam was implemented jointly with three new airport crash tenders (specialised firefighting trucks designed for use in aircraft rescue and firefighting at aerodromes) with CAFS on all low-pressure outlets.

Challenges

- Along with the implementation of the new firefighting trucks, the training of the firefighters with the new equipment and foams was a crucial issue and initial testing and training caused additional costs (exact cost estimates are unknown). Also, the different viscosity of the PFAS-free foam caused some initial challenges, which were later solved by the adjustment of equipment; and
- Some of the old trucks continued to be in use and, even though the tanks were cleaned thoroughly, a contamination of the PFAS-free foam with PFAS occurred initially.

Costs of replacement

- Upon implementation of the new fluorine-free alternative, testing and training required ~5,000 litres foam/year. However, with some modifications to the equipment and training, the volume has now been reduced to 3,000 litres foam/year. Optimal efficiency was found at a 6% foam concentration (ICAO Level C) instead of 3% (ICAO Level B), thus larger foam volumes may still be used in certain situations;
- Costs incurred in the replacement comprised mainly costs for destruction of PFAS-containing foams and additional training and testing. More specific cost estimates were not available in this case. However, it should be noted that the foam supplier also had an interest in supporting the implementation of the PFAS-free foam and carried out some of the foam testing and covered the additional costs; and
- The investment in new airport crash tenders (specialised fire engines designed for use in aircraft rescue and firefighting) was not strictly linked to the foam replacement, but the coincident introduction of new trucks and foam was seen as having a cumulative benefit.

Benefits

¹³⁸ The difference between aspirating and non-aspirating equipment is that the aspirating device mixes air in the foam/water solution within the nozzle or foam maker, whereas non-aspirating devices do not. Typical examples of non-aspirating devices are water/fog nozzles, water spray heads and conventional sprinkler heads (Ansul Technical bulletin no. 55, <https://www.ansul.com/en/us/DocMedia/F-83115.pdf>).

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- Copenhagen Airport is still working on the remediation of previous pollution from PFAS foams. In 2014, works on clean-up, containment and reconstruction of the fire training area were started and required an initial investment of more than €15 million. Currently, the maintenance of the drainage system around the fire training ground costs more than €1.5 million per year and this expenditure is expected to continue for at least the next 80 years.
- The biggest benefit of switching to a fluorine-free alternative foam is that rainwater and firewater runoff can be discharged through the normal sewer system to the municipality's waste water treatment, thus avoiding long-term clean-up issues and remediation costs in the future.

E.2.4.2. Case 2 Offshore production in Norway¹³⁹

Foams used

Equinor, representing 80% of all production on the Norwegian Continental Shelf and equivalent to 50% of total production for the North Sea, have managed to substitute PFAS-containing foams with PFAS-free foams at almost all installations. The substitution is close to completion for ~40 offshore installations and is ongoing for five onshore facilities (terminals and an oil refinery). Fire-fighting foams at offshore installations are used for multiple applications including training, system testing and emergency response of live events.

At most facilities, Re-healing RF1, 1% foam from Solberg is used, while some older facilities use Re-healing RF1 3% foam. For a few installations (where there is risk of methanol fire), alcohol resistant foam was used. The 1% and 3% foam products are used for petroleum fires and were chosen because they are regarded as a drop-in replacement for fluorinated AFFF. For methanol fires specifically, Solberg Re-Healing Foam RF3x6 ATC (alcohol resistant foam) is used.

Basically, all foam is used for training and systems testing as emergency responses are seldom (have not occurred since the implementation of the substitution). Environmental discharges may also occur due to accidental spills.

The crude oil and products are stored in caverns i.e. underground storage tanks. The typical size is 50,000 – 280,000 m³ for crude oils and 10,000 – 50,000 m³ for products. The caverns are filled up with fluids to prevent them from catching fire.

Timeline in the shift from PFAS foams to fluorine free-foams

- In 2010-2012, development and testing of a 1% fluorine-free firefighting foam was carried out as a collaborative project between Solberg Scandinavian and Equinor (named Statoil at that time). The driver for the replacement was concern of the environmental consequences of PFAS-containing firefighting foam released to the sea;
- In December 2012, the Re-healing RF1, 1% foam (RF1) was first used successfully on the offshore installation Kviteseid;

¹³⁹ Case described on based on the following sources:
IPEN position paper 2019 (https://ipen.org/sites/default/files/documents/the_global_pfes_problem-v1_5_final_18_april.pdf)

Personal communication with Lars Ystanes, Equinor, 2019

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- In 2013, the RF1 foam was technologically approved for use by Statoil after an approval and verification process;
- In 2014, approval for starting the multi-use transition project was obtained, with the aim of implementing the new foams at all Norwegian operated installations with 1% foam systems;
- By September 2016, 30 of 31 Equinor assets had successfully implemented use of RF1 foam; and
- In 2018, Solberg launched a modified 1% RF1, with lower viscosity at low temperatures and with a yellow environmental classification (compared to red classification for RF1)¹⁴⁰ called RF1-AG. This product went into operational use in 2018 on all new offshore installations.

Challenges

During the substitution implementation, several technical issues occurred which had to be resolved using additional testing by Equinor:

- During full-scale testing with RF1, a break-down of the foam proportioner occurred which was initially linked to corrosion related to the use of the RF1 foam. Further investigation identified another reason for the break-down and it was concluded that RF1 had no influence on the foam proportioners;
- RF1 has a higher density and viscosity compared to the previously used AFFF. Higher density may be a problem for installations with substandard foam pumps. However, most Equinor installations were able to handle the increased viscosity and density with only minor system adjustments. At one installation, the pumps were not able to handle RF1 and the solution for this installation is still under evaluation; and
- Initial uncertainties related to the temperature tolerance of the foam have been removed. The products currently used have a freezing tolerance down to -19°C and acceptable low viscosity at ambient temperature.

Costs of replacement

For Equinor, the total costs of substitution of PFAS-containing foams at about 40 offshore installations and five onshore facilities has been estimated to be approximately €7 million. This estimate does not include costs related to R&D, and regulatory approval costs, which were undertaken in this case by the foam supplier (Solberg). At a few facilities, adjustment of equipment was necessary, but usually, the same equipment was used and new equipment (and associated costs) was not necessary. These total headline costs can be broken down further to include the following:

- The cost for support in the multi-use phase has been estimated at 2,500 working hours in the period from August 2013 to September 2016, corresponding to a total cost of approx. NOK 3.5 million (approx. €360,000). This included activities such as planning of implementation together with the supplier, preparation of information letters, support team, follow up on technical issues, etc;
- The cost related to replacement of foam in storage ranges from €50,000 to €500,000 for the biggest oil installations, corresponding to tank storages of 20 – 120 m³. In total,

¹⁴⁰ Environmental colour marking system in Denmark and Norway of The Harmonised Offshore Chemical Notification Format under the OSPAR Convention 1992 indicating substances that should be considered and dates for substitution. "Red" substances may only be used in limited amounts and shall be substituted.

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approximately 1,100 m³ of foam was replaced over a 3 year period, resulting in a rough cost estimate of 1,100,000 litre * €5 /litre = €5.5 million. Substitution has always been done in relation to scheduled maintenance stops, turnarounds or during establishing new equipment, thus not imposing further additional costs to Equinor. Note that replacement costs listed here are not due to a higher price of alternative, but due to the costs of replacing the PFAS-based foams in storage (costs of alternatives as compared to the PFAS-based foams);

- Additionally, the cost related to destruction/incineration of old the PFAS-based foam contributed a further approx. €1 million to the transition costs (~1,000,000 litre * €1 /litre); and
- Costs of decontamination of equipment were not significant and no fire-fighting equipment or storage tanks were replaced as part of the decontamination process. The storage tanks were drained empty to >99% and the PFAS-based foams handled as waste (destruction/incineration as indicated above). Washing water containing low levels of PFAS was discharged to the sea or waste water treatment plants. Compared to continuous use of PFAS, it was considered that the small discharges of washing water were insignificant.

Costs of alternatives

The costs of the new foams as compared the PFAS-based foams used before varied between +5% to +30%, depending on foam type/application. For the majority of the foams, the costs increased by +30% and the overall costs increase was slightly below +30%.

Benefits

- At onshore installations, PFAS foams have either been released during operations at the harbour or collected as hazardous waste water at the process plants. The disposal of hazardous waste water, consisting of appr. 1% foam and 99% water meant a significant cost item before the substitution. Waste water containing fluorine-free foams is treated at the biological waste water treatment plants of the onshore installations;
- Before the substitution, PFAS-containing AFFF were always discharged to the sea during training and system test at Equinor's offshore installations. The use of PFAS-free foams now means a significantly reduced environmental impact. The annual discharge of PFAS-based foams to the sea was reduced from 3-4 tonnes to (almost) zero;
- In 2014, Norwegian authorities required standard environmental documentation for all firefighting foam used in high volumes. Since Equinor have been successful in transitioning to PFAS-free foams, there is now a general pressure driving the Norwegian market towards the use of PFAS-free foams; and
- Equinor recognise the substitution as a good investment to be in position for future regulatory changes, but they also see value in reducing their chemical footprint and strengthening their market position as substitution leaders.

E.2.5. Further analysis of alternatives

E.2.5.1. Technical feasibility

Aviation

Commented [MD59]: Another stakeholders survey targeting users is ongoing to collect further information on the technical feasibility/transition on time aspects.

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Alternatives have successfully replaced the PFAS-containing foams in a number of airports. Based on the stakeholder consultation, three different products from three manufacturers have been reported to have replaced applications of AFFF in airports in Denmark (Copenhagen, Re-healing foam RF3x6 ATC), Germany ("one of the biggest airports", Orchidex BlueFoam 3x3, Sweden (Arlanda and other airports, Moussol 3/6-FF), and the UK (Heathrow, Moussol FF 3x6). The alternatives are used for all applications. According to the IPEN report "Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams", all of the 27 major Australian hub airports have transitioned to fluorine-free firefighting (F3) foams, as have the following major hub airports: Dubai, Dortmund, Stuttgart, London Heathrow, and Manchester, Copenhagen, and Auckland¹⁴¹.

A case story from Copenhagen Airport demonstrates that some testing, modification of equipment and training has been required. The entire transition period was 6 years. Investment in new fire trucks took place at the same time, but this was not directly required due to the foam replacement.

It has been indicated by stakeholders that some airports voiced concerns over efficacy and changes of equipment, but no specific information has been obtained. The same certification tests apply for all airports in Europe and the successful transition in several airports indicates that it should be possible for others. Some alternatives comply with the highest ratings of N 1568,1A/1A for both Part 3 and 4. One stakeholder noted that high ambient temperatures can influence the performance of foams as demonstrated in an incident in Dubai. However, as mentioned above all 27 major Australian hub airports have transitioned to fluorine-free firefighting (F3) foam indicating that PFAS-free foams are also being applied at high ambient temperatures. One stakeholder (a supplier of AFFF and alternatives) with experience in transition in a German airport states that that experience from a large number of tests done in the past 10 or so years indicates it is possible to change 99.9 % of all current scenarios to PFAS-free products.

Upstream petrochemical sector

Equinor, the largest operator on the Norwegian continental shelf, has successfully replaced AFFF in about 40 offshore installations and five onshore facilities. At a few facilities, adjustment of equipment was necessary, but usually the same equipment was used and new equipment was not necessary.

At one installation, the pumps were not able to handle the alternative. The company had some challenges with the density and viscosity of the alternative foams initially used compared to the traditionally used AFFF, e.g. by lower ambient temperatures. This was solved by modifications of the alternative product. The shift took approximately eight years from the first tests to when the modified alternative was introduced on all installations.

Municipal fire brigades and forestry

PFAS-free alternatives are readily available for these areas and, as shown in the market analysis, account for more than 60% of the total market. No data on costs of substitution

¹⁴¹ Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams (AFFF), IPEN Stockholm Convention POPRC-14, Rome, September 2018

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specifically for these application areas have been provided in the stakeholder consultation or identified in the literature.

Marine applications

A wide range of PFAS-free foams are marketed for marine applications and it has not been indicated by any stakeholders that there might be particular challenges in changing to PFAS-free foams apart from the general need for adjustment and testing of equipment. One of the example products is a low expansion protein-based foam which is typically used in non-polar hydrocarbon fires in the petroleum industry and on oil tankers. It has the advantage that the product is compatible with black steel and does not require equipment made from stainless steel or plastics (and the same is the case for other protein-based products). It is designed for use with all mobile and stationary low expansion foam equipment and systems for fighting fires of classes A and B.

Military applications

Alternatives are less well established in the military sector, but it has been indicated by stakeholders that alternatives are considered to be feasible, although not many have yet been certified or implemented by users. The military applications are similar to those seen in airports and municipal fire brigades and the foams used are, after the necessary testing and adjustment of equipment, considered to be useful for military applications as well. As an example, the IPEN publication on "Fluorine-free firefighting foams (3F) viable alternatives to fluorinated aqueous film-forming foams (AFFF)" states that the Danish and Norwegian armed forces have moved to PFAS-free foams. The specific foams used have not been identified, but these are thought to be foams from major producers. As mentioned before, one stakeholder noted that testing and certification of PFAS-free foams and obtaining the necessary military approvals for use in all vessels / fire-fighting systems will take many years, and the associated costs will be very high. However, this has not been confirmed by other stakeholders.

Commented [MD60]: Add the US DoD law specifications.

Petrochemical processing and large storage tank farms

Use areas where PFAS-free alternatives have not been fully tested, is in the downstream petrochemical sector (refineries and steam crackers) and large storage tank facilities. In particular, for large storage tank fires, combatting these fires requires foams capable of flowing on large burning liquid surfaces and sealing against hot metal surfaces to prevent reignition. The development of suitable test criteria for large storage tanks and fluorine-free foams is ongoing under the LASTFIRE project. Several of the shortlisted products in this report have been tested and reported to be in compliance with the LASTFIRE criteria. According to a presentation by Nigel Ramsden, LASTFIRE, at the stakeholder workshop on 24 September 2019, it has been shown that PFAS-free foams can provide equivalent performance to C6 foams and provide appropriate performance for hydrocarbon fires in a number of test conditions:

- When used with NFPA application rates for the following applications:
 - ▶ Tank fires ~15m+ diameter (no reason to doubt results can be extrapolated to >25m+):
 - Conventional pourer standard application rates;

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- Aspirating monitor¹⁴²; and
 - “Non aspirating” monitor with appropriate foam characteristics.
- ▶ Tank fires ~60m+ diameter No reason to doubt results can be extrapolated to >80m +) or bund fires:
 - Foam pourer.
- When used at lower rates than NFPA using CAF application:
 - ▶ Tank fires ~15m+ diameter (no reason to doubt results can be extrapolated to >25m+):
 - Monitor application.
 - ▶ Tank fires ~80m+ diameter (no reason to doubt results can be extrapolated to >100m +) or bund fires:
 - Foam pourer.

It is stated in the presentation that test results for some conditions are still missing and LASTFIRE is going to work on these issues: specifically, polar solvent tests – foam application from longer distances, other foams/combinations of foam/application methods, tactics for life safety situations and optimising properties.

As indicated above, it can be concluded that even in large tanks alternatives can be applied, but the safety margin may be lower than for the PFAS-based foams. According to stakeholders, the largest risks are associated with fires in large tanks of crude oil because of the higher risk of boil-over. One stakeholder mentioned that fires in large tanks of ~40m are however very rare in the EU and they could not identify any such fires in Europe in the last 10 years.

A study by the Fire Protection Research Foundation (USA) determined the fire extinguishment and burnback times for five fluorine-free foams (FFF) and one short chain C6 Aqueous Film Forming Foam formulation (AFFF) as a function of application rate and foam discharge density for a range of test parameters including foam quality/aspiration, fuel type, water type and fuel temperature¹⁴³. In summary, the authors conclude that PFAS-free foams have come a long way but there is still a lot more to learn about their capabilities and limitations. Furthermore, they conclude: *"As of today, FFFs are not a "drop in" replacement for AFFF. However, some can be made to perform effectively as an AFFF alternative with proper testing and design (i.e., with higher application rates/densities)"*¹⁴³

No specific cases with successful 100% transition in installations with large tanks have been identified. According to stakeholders some examples exist where PFAS-free foams are used for the majority of applications but PFAS-based foams are still stored for use in emergency situations with large tank fires. A reported challenge in petrochemical processing and storage tank farms is the presence of tanks with different liquids that may require different alternatives because one alternative cannot be used for all the liquids. One supplier indicated

¹⁴² Fire fighting monitors are a controllable high-capacity water jet used for manual or automatic fire fighting

¹⁴³ Back, G.G., Farley, J.P. (2010). Evaluation of the fire protection effectiveness of fluorine free firefighting foams. Fire Protection Research Foundation.

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that in some instances in the petrochemical industry two different alternatives could be required whereas another manufacturer indicated that even more than two may be required if many different liquids are stored.

As reported elsewhere, in the chemical/petrochemical sector approximately 93% of the foam volume is used for training. Most of the manufacturers provide PFAS-free training foams that mimic the AFFF and which are used for training. One manufacturer indicated that the PFAS-free training foams were not used in live-fire training ("hot training") As indicated in the market analysis, PFAS-free alternatives account for 19% of the volume used in the chemical/petrochemical sector, but a major part of this is likely to be for training purposes.

However, in terms of performance of PFAS-free foams, a study published January 2020 by the US Fire Protection Research Foundation¹⁴⁴ concludes after comparative testing of both types of foams that:– "The AR-AFFF performed well against all test fuels included in this assessment (IPA, Heptane, and Gasoline (MILSPEC and E10). The F3s did well against heptane but struggled against some of the scenarios conducted with IPA and gasoline (both MILSPEC and E10), especially when the foam was discharged with a lower foam quality/aspiration. The F3s required between 2-4 times both the rates and the densities of the AR-AFFF to produce similar results against the IPA fires conducted in with the Type II test configuration. During the Type III tests, the F3s required between 3-4 times the extinguishment density¹⁴⁵ of the AR-AFFF for the tests conducted with MILSPEC gasoline and between 6-7 times the density of the AR-AFFF for the tests conducted with E10 gasoline. From an application rate perspective, the F3s typically required between 1.5 to 3 times the application rates to produce comparable performance as the baseline AFFF for the range of parameters included in this assessment "

Referring to this study, Eurofeu indicated¹⁴⁶ that this has significant implications for users:

- Increased storage volume of foam concentrate;
- Bund areas in tank farms may need to be retrofitted to cover a significantly higher volume of liquids, associated with an emergency response action;
- Significantly increased firewater retention capacity is required, which can cause reasonable difficulties in retrofitting operating sites to the new demand;
- Cut-back on tank storage capacity to leave sufficient space for additional firefighting agent application: Tank owners may have to reduce the maximum stored volume in tanks to leave enough space for containment of an increased amount of firefighting foam;
- Studies of the US Naval Research labs¹⁴⁷ clearly indicate that F3 require significantly higher application rates (see above).

This indicates that, even though fluorine-free foams seem to overall perform well against different types of fuels, different application rates and methods may be needed to achieve

¹⁴⁴ "Evaluation of the fire protection effectiveness of fluorine free firefighting foams", Fire Protection Research Foundation report, January 2020; <https://www.nfpa.org/News-and-Research/Data-research-and-tools/Suppression/Evaluation-of-the-fire-protection-effectiveness-of-fluorine-free-firefighting-foams>

¹⁴⁵ The authors describe the "extinguishment density" as the total amount of foam needed to extinguish a fire of a given size.

¹⁴⁶ Comment #2893 to the PFHxA restriction proposal: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

¹⁴⁷ "Fuel for Firefighting Foam Evaluations: Gasoline vs Heptane", Naval Research Laboratory, June 2019, <https://apps.dtic.mil/dtic/tr/fulltext/u2/1076690.pdf>

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the desired effect, resulting in the need to implement several technical adaptations to the overall fire extinguishing system of a site, including foam storage tanks and bunds. Sufficient time is therefore needed to allow users to implement these technical adaptations to transition to PFAS-free alternatives in order to maintain the necessary fire safety levels.

According to a chemical company having commented the PFHxA restriction proposal on 26/06/2020, to their knowledge, there has not been any major Class B fire (e. g. in a tank farm of a processing plant in chemical industry) that was extinguished using PFAS-free foams yet¹⁴⁸. They further indicated that there has been a very limited number of larger-scale tests made by LASTFIRE since 2018, so there is not enough evidence on transferability of small-scale test results for Class B fires to large-scale Class B fires. This poses the risk that a given Class B fire cannot be controlled using fluorine-free foam and the tank needs to be burnt down with all socioeconomic consequences including loss of reputation which both need to be prevented. The company raised also the following issues:

- Fixed and semi-fixed extinguishing systems e. g. for tank farms and tank pits might require a general overhaul when switching to fluorine-free foams.
- Fluorine-free foams require significantly higher application rates which cannot easily be achieved in existing installations. This can result in the need to partial or complete exchange of foam extinguishing systems with large capital invest.
- Increased fire knock-down times and application rates will also lead to insufficiently dimensioned firewater retention systems, such as diked areas around tank farms or processing plants configured for AFFF-AR¹⁴⁹ use. Diked areas usually cannot be heightened in existing structures due to technical constraints. If constructional changes are possible at all, they usually require disproportionate financial efforts.
- Increased firewater demand might require infrastructural changes throughout chemical sites that cannot be realized due to disproportionate financial efforts.
- If changes need to be made to semi-fixed, fixed and mobile equipment, at least a decade will be needed for planning, budgeting and execution of the resulting projects.
- Processing plants and warehouses pose similar risks as tank farms, as they can contain large quantities of flammable liquids potentially spreading to the plant pit or within the warehouse with surface area > 500 m²

However, other stakeholders of the same sector did not report the need for such large infrastructure overhaul.

¹⁴⁸ Comment 3046 – see in “Part 3” document available at <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

¹⁴⁹ AFFF-AR: Alcohol-resistant aqueous film forming foam

E.2.5.2. Availability

A large number of alternatives are available from at least eight manufacturers. Most of these manufacturers also manufacture AFFFs and the alternative product range is often designed to match the product range of AFFFs. As demonstrated with the successful transition in many airports, products from several manufacturers are applicable for replacing the AFFF for the same application. Only limited information on actual production volumes for the individual products has been available from manufacturers because this information is generally considered confidential. The PFAS-free alternatives currently represent 32% of the market and this share is growing.

Based on interviews with three manufacturers of fire-fighting foams in Europe, it can be concluded that there is currently overcapacity in Europe e.g. one of the manufacturers indicated they are running at 10-20% of their capacity. One manufacturer indicated that they have also extra capacity for emergency situations. All three manufacturers estimated that the necessary volumes of alternatives could be supplied within a short time (one to a few years). All EU manufacturers are also formulators and the alternative products are formulated from common bulk raw materials for cleaning and washing agents, food products, etc. and not specifically produced for the alternative firefighting foams. The manufacturers indicated that raw materials are available in sufficient quantities. According to the manufacturers and other information from stakeholders, the main challenge in the transition would not be to meet the demand for those alternatives already on the market, but to develop alternatives for application areas where replacement is still challenging.

E.2.5.3. Health and environmental risks

For the shortlisted products, none of the components included in the Safety Data Sheets are classified with CMR properties. For most of the products, the Safety Data Sheets indicate that the products or components do not meet the PBT/vPvB criteria of REACH. For two products, it is reported in the Safety Data Sheet that sufficient data are available for assessing whether the components fulfil the PBT and vPvB criteria. None of the products, however, include substances demonstrated to be PBT or vPvB substances. The classification of the components of assessed alternatives indicates that other classified effects are "Causes skin irritation" (H302), "Causes serious eye irritation" (H319) and "Causes skin irritation" (H315). Many of the products do not include substances classified with environmental effects whereas others include one or more substances classified "Harmful to aquatic life with long lasting effect" (H412). It should be recognised however that not all human health or environmental hazard endpoints have necessarily been assessed in detail for each component by the foam manufacturers (for example, endocrine disrupting effects).

Standards for firefighting foams have been developed by GreenScreen®¹⁵⁰ and several foam products have been assessed under this framework and attributed bronze and silver level scores¹⁵¹.

Commented [MD61]: Add info on high BOD and kill of fishes.

¹⁵⁰ <https://www.greenscreenchemicals.org/certified/fff-standard>
¹⁵¹ <https://www.greenscreenchemicals.org/certified/products>

E.2.5.4. Economic feasibility

The available data indicates that the most significant one-off costs to transition to fluorine-free foams are associated with the following:

Replacement of foams in storage. For Equinor, the costs of replacement of AFFFs was €5/l corresponding to €5.5 million;

Destruction of replaced AFFFs. In addition to costs of about €1/l for the destruction of the replaced AFFFs, corresponding to a total of €1 million;

Decontamination of equipment. The available cases do not indicate significant costs of decontamination of equipment. The equipment has typically been drained and decontaminated by cleaning with washing water which was discharged to waste water or surface water. However, the costs of cleaning of equipment will depend on the requirements as to the decontamination level and discharge of cleaning water. According to information from manufacturers, it may in some instances be less expensive to change part of the equipment than to clean it especially for stationary equipment. Stakeholders have reported, the requirements are different between Australia and New Zealand resulting in large differences in the costs of decontamination of equipment (specific data have not been obtained);

Management of the transition process. Reported at €0.36 million for Equinor i.e. less than 10% of total transition costs;

R&D and regulatory approval costs. These costs are usually covered by the manufacturers of foams and reflected in the price of the alternative foams;

Adjustment and replacement of equipment. The available cases indicate that the costs of replacing equipment has been small in comparison to the cost elements listed above. According to stakeholders, extra storage capacity is not always required; and

Training in the use of new products. The available cases do not indicate additional training costs; these are covered by the costs of testing and adjustment of equipment.

Regarding the effective price of alternatives, three interviewed manufacturers of PFAS-based foams and alternatives consider that the effective price is more or less the same and within +/- 20%. In accordance with this, additional recurrent costs for alternatives used in the aviation sector, stakeholders have reported that the effective price of the alternatives (taking efficiency of alternative into account) is more or less the same as the price of the AFFF used before the transition. The case from the offshore sector reports extra costs varying between +5% and +30% depending on application with total extra costs slightly below +30% as compared with the AFFFs used before. This may reflect the more diverse scenarios in the offshore petroleum sector.

The reported shelf lives of alternatives range from >10 years to 20 years. Shelf life of PFAS-based foams is reported to be typically between 10 years and 20 years (to a maximum of 30 years)¹⁵². In general, the shelf life of the alternatives does not seem to be shorter than the

¹⁵² Proposal for a restriction: Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related substances
<https://echa.europa.eu/documents/10162/a22da803-0749-81d8-bc6d-ef551fc24e19>

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shelf life of PFAS-based foams and no extra costs, as a consequence of differences in shelf life, have been indicated by stakeholders.

The main advantages of using alternatives in the aviation sector are that the rainwater and firewater runoff from training grounds can be discharged through the normal sewer system to the municipality's waste water treatment system, thus avoiding long-term clean-up issues and remediation costs in the future. The case from Copenhagen airport demonstrates that works on clean-up, containment and reconstruction of the fire training area were started and required an initial investment of more than €15 million, and currently, the maintenance of the drainage system around the fire training ground costs more than €1.5 million per year and this expenditure is expected to continue for at least the next 80 years.

At offshore installations, training foams are typically discharged directly to the sea and it is not considered feasible to avoid this discharge by collecting and treating the AFFF-containing firewater.

As indicated above, the costs of destruction of PFAS-based foams is about €1/litre (a more detailed description of destruction costs is provided in section E.4). The costs of destruction of the PFAS-based foams is likely to be incurred in any case when the foams expire (exceed their shelf life). In the past the PFAS-based foams were also used for training which meant that stocks were used before they reached the end of their shelf life. According to information from stakeholders it is today common to store PFAS-based foams which have reached their shelf-life whilst waiting for a less expensive solution for disposal. In a scenario where PFAS-based foams are used for emergency situations and PFAS-free foams are used for training, a cost of about €1/litre for destruction of the PFAS-based foams by the end of their service life should be expected.

E.2.5.5. Comparison of application area

An overview comparison of the use of fluorine-free alternatives in different applications is provided in the table below:

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Parameter		Questions	Airports	Off-shore facilities	Petrochemical industry and large tank farms	Municipal fire brigades	Marine applications
Technical feasibility		Can alternatives perform the same functions as the PFAS-based foams for same application	Training: Yes Actual fires: Yes	Training: Yes Actual fires: Yes	Most training scenarios: Yes Large-scale fires: Not demonstrated for some situations	Training: Yes Actual fires: Yes	Training: Yes Actual fires: Yes
		Will it require changes (in processes, equipment, storage facilities, training, etc.)?	Adjustment of equipment, tests, training required. In some instances there may be a need for new equipment and increased storage capacity				
Availability	Current and future availability Timeframe	Is it available in the required tonnage / amount in the EU / worldwide?	Yes	Yes	Yes for most training No - further tests of alternatives required for actual emergency situations in large tank farms and some other installations	Yes	Yes
		How fast could enterprises make the switch? What would be the downtime, if any?	Meeting market requirements not considered a challenge as transition is expected to take some years	Meeting market requirements not considered a challenge as transition is expected to take some years	No challenge for training foams Further development required for large tank farms	Meeting market requirements not considered a challenge as transition is expected to take some years	Meeting market requirements not considered a challenge as transition is expected to take some years
Risks	Human health	Information on the hazards: properties causing the concern for the substance to be restricted / other properties.	None of the constituents of the alternatives meet the CMR criteria. Classification of constituents of alternatives does not point to any significant health concern. This assessment is based on hazard information identified in safety data sheets for relevant products. The safety data sheets include constituents with a hazard classification, and the conclusion that the alternatives do not meet the CMR criteria are considered robust for the foams evaluated in more detail. However, there was insufficient information to conclude whether the underlying test/endpoint data was equivalent for these substances and the alternative products compared to the PFAS-based products				

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Parameter	Questions	Airports	Off-shore facilities	Petrochemical industry and large tank farms	Municipal fire brigades	Marine applications
Risk to the environment	Information on risks related to properties causing the concern for the substance to be restricted / other properties. Information on other risks related to the alternatives.	Some constituents are classified with hazard phrases such as harmful if swallowed and causes serious eye irritation and occupational exposure should be reduced by use of adequate protective equipment, but this would likely apply to any fire-fighting foam.				
	Information on the hazards: properties causing the concern for the substance to be restricted / other properties.	PFAS are very persistent with a potential for exposure of humans via the environment. Short-chain PFAS accumulate in edible parts of plants and the accumulation in food chains is unknown ¹⁵³ In general, there is a high level of uncertainty as to whether the ongoing exposure to low concentrations of short-chain PFAS may cause adverse effects in organisms. It is therefore very difficult to estimate long-term adverse effects in organisms.				
	Information on risks related to properties causing the concern for the substance to be restricted / other properties. Information on other risks related to the alternatives.	The constituents of alternatives are in general not persistent, and exposure via the environment is not considered to be of concern based on data currently available. For some alternatives, data are not sufficient to conclude that they do not include persistent constituents.				
Assessment of net risk	Would the alternative result in a sufficient reduction in the net risk? Are there new risks associated with the alternative?	Alternatives do not generally meet the PBT or vPvB criteria. For some of the alternatives, data were not sufficient to determine whether some constituents are persistent. Many of the alternatives include constituents classified as toxic or very toxic to aquatic life.				
		Short-chain PFAS are very persistent with high mobility in environmental media and high potential for long-range transport. * The constituents of the alternatives are in general not identified as persistent or of having a high potential for long-range transport and for accumulating in the environment. However, there was insufficient information available to conclude whether the underlying test/endpoint data was equivalent for these substances and the alternative products, compared to the PFAS-based products.				
		In general, alternatives do not contain very persistent substances and are considered likely to provide a reduction in the net risk. The main constituents of alternatives are typically used in cleaning and washing agents, food, etc. Overall, no significant new risks have been identified based on the available information. However, not all human health or environmental hazard endpoints have necessarily been assessed in detail for each component by the foam manufacturers (e.g. endocrine disrupting effects). Additionally, the level of information available on the risk posed by some alternatives is insufficient to conclude whether the underlying test/endpoint data was equivalent compared to the PFAS-based products.				

¹⁵³ Short-chain perfluoroalkyl acids: environmental concerns and a regulatory strategy under REACH. Brendel et al. 2018. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5834591/pdf/12302_2018_Article_134.pdf

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Parameter	Questions	Airports	Off-shore facilities	Petrochemical industry and large tank farms	Municipal fire brigades	Marine applications
Economic feasibility	Net costs	One off costs: The main costs of transition are reported to be costs of replacement of PFAS-containing foams in storage and destruction of these foams (such costs would not normally have been incurred outside of normal replacement after 10-20 years). Total costs of replacement and destruction is approximately €6/l. Costs of decontamination of equipment have been mentioned by stakeholders as potentially significant, but actual cases do not indicate significant costs of decontamination. Recurrent costs: Extra costs of foams are reported to be in the range of 0 to +30%.				
	Economic feasibility of the alternatives.	Alternatives have successfully been implemented by many users	Alternatives have successfully been implemented by some users	Alternatives have successfully been implemented for training purposes; for specific applications alternatives are not available	Alternatives have successfully been implemented by many users	Alternatives have successfully been implemented by many users
	Ability of the different actors to pass costs down the supply chain.	High (no competition with competitors outside the EU)	Medium (some competition with competitors outside the EU)	Medium (some competition with competitors outside the EU)	High (no competition with competitors outside the EU)	Low (significant competition with competitors outside the EU)
	Trade and wider economic and employment effects.	No effect expected	No significant effect expected	No significant effect expected	No effect expected	No significant effect expected
Uncertainties.	What is the level of uncertainty in the assessment of the feasibility, risks and economic viability of alternatives?	High certainty	High certainty	Medium certainty - many different and complex scenarios	High certainty	High certainty

E.3. Restriction scenario(s)

See Section 2.3.

E.4. Economic impacts

E.4.1. Socio-economic analysis

Section 2.3 summarises the main effects (i.e. anticipated responses from the supply chains along with associated impacts) resulting from the two restriction scenarios and identified the ultimate impacts to be assessed. These ultimate impacts are described below.

4.1.1. Cleaning of equipment: costs and remaining contamination

A restriction on the placing on the market of PFAS-containing fire-fighting foams (RMO 1) would allow users to continue using their stocks of foams, but once they are depleted, users would be forced to switch to alternative (fluorine-free) foams. A restriction on the use of PFAS-containing fire-fighting foams (RMO 2) would require this switch to happen immediately when the restriction comes into force (or before).

During the storage of PFAS-containing foams, fluorinated surfactants settle on the walls of the tanks as well as in pipe and hose lines of fire-fighting equipment. These would leach into any new foams filled into the equipment and therefore contaminate the new fluorine-free foams with PFAS, leading to continued PFAS emissions¹⁵⁴. In order to control these emissions, equipment previously used for PFAS foams may be required to meet a minimum concentration limit of remaining PFAS, which can potentially be achieved through cleaning. This sub-section discusses the feasibility of achieving certain remaining concentrations of PFAS through the cleaning of equipment, with a focus on the associated cost. The analysis of alternatives has concluded that currently available cases of transformation to fluorine-free foams do not indicate significant costs of decontamination of equipment (including disposal of the liquid used for cleaning), with relatively simple methods being applied. However, the costs of cleaning of equipment will depend on the contamination thresholds requirements. According to information from manufacturers, it may in some instances be less expensive to change part of the equipment than to clean it, especially for stationary equipment, so this is also discussed below.

Wood (2020) identified the following techniques to clean PFAS-containing foam from equipment are:

- The use of **hot water and detergents** in a 32-stage legacy foam decontamination process (stakeholder consultation response). This technique is reported to result in all appliances achieving PFAS levels below 1000ppt and one-third of appliances being below 70ppt. An independent body oversees the

¹⁵⁴ Bavarian Ministry of the Interior, Sport and Integrat on, and Bavarian Ministry of the Environment and Consumer Protection: Environmentally friendly use of fire-fighting foams. Available at: [https://www.bestellen.bayern.de/applicat on/eshop_app000000?SID=578672032&ACTIONxSESSxSHOWPIC\(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27\)](https://www.bestellen.bayern.de/applicat on/eshop_app000000?SID=578672032&ACTIONxSESSxSHOWPIC(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27)) [In German]

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process and measures the PFAS concentrations achieved. The approximate cost of this process is **€12,300¹⁵⁵ per appliance**.; and

- For stainless steel tanks, glass fibre reinforced plastic and polyethylene tanks, following the discarding of the foam, **tanks are rinsed with hot water (50-60°C) and then filled again with hot water for at least 24 hours¹⁵⁶**. This process is repeated three times in both the tank and any foam carrying pipes and fittings, and the water from these rinsing operations passed into the sewage system and treatment plant. This is recommended in some government guidance¹⁵⁷. No information could be identified concerning the costs of this technique or the remaining contamination levels achieved.

Several stakeholders commented on the feasibility of cleaning techniques to remove PFAS-containing foams from equipment. One stakeholder considered achieving PFAS contamination levels below 100 ppb to be unrealistic in most cases (from the Helsinki September 2020 stakeholder workshop) and one stakeholder considered it to be almost impossible to achieve a contamination level of zero in a one-digit ppb framework with another stakeholder also commenting that the cleaning of systems and equipment is unlikely to bring the level of residual PFAS to zero. One stakeholder that has transitioned to fluorine-free foams (in the petrochemicals sector) reported that they had aimed for and achieved a level of 0.001% (10,000 ppb). To put this into context, the average concentration of PFAS in PFAS-based fire-fighting foams is some 2-3% (20-30 million ppb). One stakeholder commented that the level of cleanliness achieved by cleaning techniques would vary depending on the equipment and material being cleaned. The need to accommodate an allowance for residual legacy PFAS even after equipment has been cleaned was also discussed.

Stakeholders also commented on how cleaning techniques and costs may be impacted by different PFAS contamination thresholds. Where contamination threshold levels are set high, following the cleaning of equipment, a higher level of residual PFAS-containing foam would be allowed to remain (compared to if a lower threshold limit were set). One stakeholder therefore considered the implementation of a high contamination threshold to be “pointless”, due to its reduced effectiveness in eliminating PFAS emissions. With a low contamination threshold level, a lower level of residual PFAS-containing foam will be allowed to remain in equipment following cleaning and cleaning will be more costly than if a higher threshold level were set. Also, where contamination levels cannot be achieved through cleaning, equipment will need to be replaced at a cost. Equipment replacement is more likely to occur where threshold levels are set low.

There are potentially significant costs associated requirements for cleaning or replacement of equipment, if a low threshold is set for residual PFAS concentrations (following use of the alternatives in the same equipment as PFAS-based products). The market analysis (Annex A) estimated that there are likely to be several tens or **potentially hundreds of thousands of facilities with equipment that contains fire-fighting foams**. If all of these require extensive cleaning using techniques such as the decontamination process described above (and costing €12,300 per appliance), the costs of cleaning could be in the region of €1 billion (based on an assumed 100,000 appliances needing cleaning). If a less stringent threshold concentration is used, the costs would potentially be significantly lower.

¹⁵⁵ Convers on rate of 1 EUR = 1.62470 AUD applied. It is assumed that this cost includes treatment of the waste water generated, although the stakeholder response did not specify that.

¹⁵⁶[https://www.bestellen.bayern.de/application/eshop_app000000?SID=578672032&ACTIONxSESSxSHOWPIC\(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27](https://www.bestellen.bayern.de/application/eshop_app000000?SID=578672032&ACTIONxSESSxSHOWPIC(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27) [In German].

¹⁵⁷[https://www.bestellen.bayern.de/application/eshop_app000000?SID=147496132&ACTIONxSESSxSHOWPIC\(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27](https://www.bestellen.bayern.de/application/eshop_app000000?SID=147496132&ACTIONxSESSxSHOWPIC(BILDxKEY:%27stmuv_all_00001%27,BILDxCLASS:%27Artikel%27,BILDxTYPE:%27PDF%27) [In German]

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Regulation in Queensland, Australia, allows for threshold concentrations for replacement foam stocks to be 10ppm (mg/l) for PFOA/PFHxS and 50ppm (mg/l) for PFOA¹⁵⁸. Additionally, one stakeholder commented that newer C6 foams are purer and have lower concentrations of impurities than older C6 foams and suggested that different threshold levels for different PFAS-containing foams may be required.

For confirmation that threshold levels have been achieved, cleaning techniques may need to be professionally endorsed or, following cleaning, the presence and concentration of remaining PFAS tested. Stakeholder responses **reported some concern over the suitability of existing methods to measure and detect the presence and concentration of remaining PFAS**. One stakeholder reported that measuring very low concentrations e.g. at ppb-concentration was not possible. One stakeholder suggested that following cleaning, an assessment should be undertaken at an accredited laboratory for verification that threshold levels have been achieved. Stakeholder responses suggested that laboratories are able to analyse down to a level of 30-150 ppb. In the REACH restriction on PFOA, a concentration limit of 25 ppb of PFOA including its salts or 1,000 ppb of one or a combination of PFOA-related substances was adopted, based on the capabilities of analytical methods according to the RAC's opinion on the restriction dossier. Information on the cost of analysis was not provided. A cost analysis concerning the measurement of cleaning success could therefore be done as part of this analysis.

Where threshold limits cannot be achieved through cleaning techniques or where cleaning techniques are too difficult or too costly to achieve, the replacement of equipment is likely to be required. The cost of replacing equipment will vary across industries and appliances. Table E.1 provides an example of the potential costs for the replacement of fire extinguishers, where cleaning techniques do not succeed in attaining threshold concentration levels, or the cleaning process costs more than the cost of replacement. It is assumed that these costs represent only the replacement cost of the equipment and do not include the replacement cost of equipment plus foam, nor the cost of disposal of the old equipment. Figures for the total number of fire extinguishers existing and currently using PFAS-based foam have been obtained from the Market Analysis (the lower end of the range is based on a Eurofeu position paper and the higher end considered a more uncertain high-level estimate based on extrapolation from German data and expert judgement). The stakeholder consultation also revealed that the cost for a new extra foam tank in a fire truck is €35,000 for a fire brigade providing industrial fire protection. However, information of the number of existing foam tanks containing PFAS fire-fighting foam was not provided and therefore cost analysis for their replacement has not been estimated.

Table E.1 Estimated costs for the replacement of fire extinguishers in the whole of the EU

	€1 per replacement extinguisher	€3 per replacement fire extinguisher	€5 per replacement fire extinguisher
15 million fire extinguishers to be replaced	€15 million	€45 million	€75 million
90 million fire extinguishers to be replaced	€90 million	€270 million	€450 million

Note that these costs do not include the cost of foam disposal from cleaning. Estimated costs of fire extinguishers were obtained from stakeholder consultation and it is not clear whether the costs of fire extinguisher replacement

¹⁵⁸ Obtained from stakeholder consultation. Also available online here: <https://www.qld.gov.au/environment/pollution/management/disasters/investigation-pfas/firefighting-foam/policy-overview>

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include the cost of alternative fire-fighting foam, as well as the equipment. Costs of fire extinguishers range from €1-5, and have been interpreted as low (€1), medium (€3) and high (€5). All fire extinguishers are assumed to cost the same regardless of size and capacity.

Overall, stakeholders considered the cleaning of equipment to be a costly operation, but little quantification of costs was provided in the consultation, making it difficult to undertake a cost analysis. Several users have already transitioned from using PFAS-containing firefighting foams to PFAS-free firefighting foams. Several consultees report there to be no significant costs associated with new equipment required. Although some stakeholders also report the replacement of fire-extinguishing systems and the cleaning of equipment to be costly. The cost of cleaning existing equipment will likely depend upon how effective cleaning techniques are for each appliance, as well as on the threshold contamination levels set. Where equipment cannot be sufficiently cleaned to meet threshold contamination levels, replacement will be required.

An additional stakeholders survey and literature search was conducted by Ramboll in 2021 to collect more information on the methods and costs of equipment cleaning. The outcome summary is presented below and a more extended description of the cleaning techniques is presented in section Y.

Description of the problem

PFAS are known to settle and accumulate on vessels and equipment, which, if not taken care properly, leads to the contamination of new fluorine-free foam. In more detail, PFAS adhere to surfaces and are known to self-assemble in multiple layers to coat surfaces forming a waterproof coating (JOIFFF 2020).

Thus, PFAS chemicals would continue to be released into the environment during operations. Therefore, before using any stationary or mobile equipment, that has already been used for the PFAS foam, it is necessary to clean or dispose and replace the equipment that cannot be cleaned (JOIFFF 2020). According to Arcadis, there is a common misconception that repeat washing of fire suppression systems with water can effectively remove PFAS, as for example after a few rinses, less PFOS may be detected in rinse water. However, PFASs can as explained above form a waterproof coating on surfaces, so PFAS concentration in the rinse water will not be representative of that still remaining entrained within fire suppression systems (JOIFFF 2020). According to Arcadis fluorine free foams (F3) foams used to replace C8/C6 foams become contaminated with PFASs over time. After years of holding AFFF concentrate, the surfaces of piping system components including pipe, fittings, valves, and tanks are coated with self-assembled PFAS which slowly dissolve into the replacement F3 foam.

In addition to the replacement and cleaning of PFAS and PFAS-contaminated equipment, it is current knowledge and has been raised also during interviews, that minor modifications to existing fire protection systems are commonly required with foam replacements to ensure appropriate standards for proportioning and flow requirements are achieved, and often to maintain accreditation for insurance coverage (Interview 2021; Equinor-Ystanes-Interview 2021; JOIFFF 2020). To ensure proper performance, it is now common practice for existing foam proportioners to be replaced with units tested and accredited with the replacement foam. For most cases, performance requirements cannot be achieved without the tested and certified proportioner. Foam application rate and discharge duration are often impacted by the differing physiochemical properties of the replacement foam. One clear example is kinematic viscosity, which will affect the performance of pumps and storage volumes of concentrate. The switch to aspirated discharge devices typically increases replacement foam performance and reduces the need for more extensive system modifications.

Commented [MD62]: To check if this is still true, based on Ramboll's information.

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Different institutions (manufacturers, remediation companies, public authorities) define guidelines and instructions for the cleaning process, which fire departments and companies can make use of. Based on current literature and stakeholder input, the following passages encompass current go-to techniques. In some cases, the described techniques are the same as for the disposal of PFAS-contaminated fire run-off or cleaning water described in [section X](#). Here, only information to the cleaning of equipment is highlighted.

“Non cleaning”

There is no official guideline that lays out the practical details the transition from PFAS-based foam to fluorine free foam, describing for example cleaning procedures and accepted remaining levels. Thus, companies and fire brigades have been developed their own replacement strategy. Based on the input of stakeholder this included, in comparison to “cleaning techniques”, no washing steps with water.

One stakeholder from Germany shared their experiences after transition from C8-based foam (3M Lightwater which is supposed to be based on PFOS) to C6-based foam without a cleaning procedure. After the replacement, the C6-based foam was tested for its PFAS content and high concentration of PFOS were found. In the end this observation led to the development of a cleaning procedure specialized on foam concentrate tank located at industrial fire brigades. This procedure is explained in detail in [section X](#).

Another stakeholder from Norway stated that when a first round of replacement of PFAS to non-fluorine foam took place, no official cleaning protocol has been used. The PFAS-foam was simply drained and new foam (fluorine free) was filled in. However, follow-up measurements then showed that PFAS were still detectable.

In terms of replacement procedure, according to one stakeholder, the PFAS-foam was simply drained and new foam (fluorine free) was filled in. No more information available.

The remaining PFAS concentrations from legacy C8-contamination levels as measured by the PFOS-concentration were reported to be 28.000 µg/kg (which is higher than the threshold of 10,000 µg/kg according to the POP-regulation (10 ppm)). The stakeholder from Norway used a limit is 0,001% (10 ppm) PFAS and had to refill tanks twice in a couple of cases to get below this limit. No information on costs of the actual replacement strategy was available. Secondary costs are due to the incineration of the replaced foam.

As highlighted above, both stakeholders have been faced with contamination of the new foams with legacy PFAS-substances (like PFOS). Based on this contamination both stakeholders decided to develop cleaning strategies and had to start the process again.

Conclusion on available cleaning procedures for firefighting equipment

The following conclusions can be made for available cleaning procedures for firefighting equipment:

- The procedures described in this report were authored by regional (Germany) and national (Australia) authorities, private companies (PerfluorAd & Arcadis), associations and lastly by manufacturers of foams (BioEx).
- All of them use extensive cleaning steps with (sometimes hot) water, which can also soak in overnight

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- The commercial technique uses also cleaning agents which precipitate the PFAS
- In some a replacement of highly contaminated material is suggested to avoid high remaining PFAS-concentrations
- The success (remaining PFAS concentration) is measured using a variety of analytical techniques and respective PFAS-species.
- Most of the procedures are for fire brigade vehicles and/or tanks. Cleaning costs are reported to be between 4 000 and 200 000 Euro per vehicle. The highest costs are reported when using the LfU-Guideline. In this case costs of 100.000-200.000 € and remaining PFAS levels in the range of 10 ppt are cited. When using the PerfluorAd-cleaning procedure costs between 20 000 and 25000 Euro per vehicle and a remaining PFAS level of 0.001 µg/l (0,001 ppm) are reported. Around 4000 € are reported by the WFVD (in this case no costs for employees is considered as is foreseen that the firefighters will clean the tanks). The achievable concentration is reported with 57 µg/L (0.058 ppm).
- Two procedures are also claiming to be suitable to installed firefighting systems (sprinklers). However, in this case only very limited data is available. According to a stakeholder from Germany, [REDACTED] his company is receiving only for 6-12 months requests for cleaning installed systems. He also pointed out that, the PFAS-concentrates normally are contained in the tank, tank to mixer pipes, and finally the mixer (if there has been no incidents/training with PFAS-containing firefighting foam).
- A large company in the chemical sector indicated that there would be costs of around **1.500.000 € per installed system**. However, in this case no remaining PFAS-concentration is named.
- According to Eurofeu, the transition from fluorine-containing foam agents to fluorine free ones in fixed installed systems, trucks and storage facilities requires a much more in-depth cleaning compared to a like for like foam agent exchange. This factor particularly heavily depends on the thresholds to achieve. However, the cost for cleaning including disposal cost for foam agents and cleaning residues as well as replacement of systems or parts thereof are considered to be very high and have a high potential to grow exponentially depending on the conditions to reach (Eurofeu 2020).
- In most cases, incineration of the cleaning water is recommended
- Only very limited data for long-term success of cleaning procedures

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Table X: Comparison between cleaning procedures

	Cleaning Procedure BIOEX	Cleaning Procedure AngusFire	Cleaning Procedure Arcadis	Cleaning Procedure PerfluorAd	Cleaning Procedure LfU	Cleaning Procedure FRV	Cleaning Procedure FPA AUS	Cleaning Procedure DoD AUS	Cleaning Procedure WFVD
Party	Foam manufacturer	Foam manufacturer	Consultancy	Company	Authority	Fire brigade and workers association	Authority	Department of Defence Australia	Association
Background	Cleanout protocol is recommended in case downstream users don't want to replace pump and storage tank.	Cleanout protocol is recommended when foams should be replaced. It is not a decontamination strategy.	Protocol uses specialized biodegradable cleaning agents such as V171	Protocol uses specialized cleaning agent (PerfluorAd).	Cleaning instructions of equipment when transitioning to fluorine-free foam extinguishing agents	Cleaning procedure developed a decontaminate procedure for appliances (fire trucks).	Fire Rescue Victoria and the United Firefighters Union developed a decontaminate procedure for appliances (fire trucks).	Transition of all Army, Air Force and Broadspectrum firefighting vehicles to a suitable Fluorine Free Foam (F3) product	Foam concentrate tank cleaning procedure, that cleans the tanks accordingly and transition to fluorine free foam
Cleaning procedure (short)	Simple replacement including scrubbing and hot water rinsing	Simple replacement including water rinsing	Cleanout protocol uses a sequential series of aqueous rinses high-pH flushes and application of the cleaning agent.	Cleanout protocol uses flushing with PerfluorAd Agent.	Simple replacement including water rinsing until no foam is detectable	32-stage decontamination process including exhaustive water rinsing	Simple replacement including water rinsing	Detailed decontamination process including exhaustive water rinsing	Simple replacement including water (hot) rinsing
Equipment	Tanks	Tanks	Fire brigade vehicles and for stationary fire extinguishing system	Fire brigade vehicles and for stationary fire extinguishing system	Tanks	Fire brigade vehicles	Tanks	Fire brigade vehicles	Fire brigade vehicles
Final disposal addressed?	Yes, but only for the foam.	Yes, high temperature incineration	Yes, high temperature incineration	Yes, high temperature incineration	Yes, high temperature incineration	Yes, high temperature incineration	Yes, high temperature incineration	Yes, according to local regulation	Yes, high temperature incineration
Remaining PFAS concentration	No information	No information	Final water flush/rinse contained around 0.1	Final rinse with fresh water contained less	Final rinse with water contained 10 ng/l (10 ppt)	Final rinse with water contained 70 ppt as measured by sum	Final rinse with water contained 70 ppt as	No information	Final rinse with water contained around low

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			µg/l PFAS as measured for the sum of 28 PFAS (according to TOP 4 µg/l)	than 1.0 µg/l total PFAS very often less than 0.3 µg/l to 0.0 µg/l can be achieved.	of each of the 13 standard PFAS (according to German DIN standard).	of PFOA and sum of PFHxS and PFOS	measured by sum of PFOA and sum of PFHxS and PFOS		µg/l of each of the 13 standard PFAS (according to German DIN standard)
Costs	No information	No information	No information	20 000-25 000 Euro per vehicle (incl. wastewater handling)	100-200 000 € per vehicle (permanently installed tank in the vehicle is cleaned)	No information	No information	No information	Around 4 000 Euro per vehicle
Additional information	No information	No information	Limited case studies information by provider.	Procedure should be followed by GAC or incineration of water. Accreditation by German authorities.	Used in Bavaria (Germany) for several municipal fire brigades.	Over 145 FRV and firefighting appliances and over 150 kms firefighting hoses have been decontaminated	No information	No information	No information

4.1.2. Other options than substitution and their impacts

This section discusses what other responses to a restriction than using alternatives are likely (if any), and their socio-economic impact. Theoretically, in response to PFAS-based fire-fighting foams becoming unavailable, users could respond by eliminating the need for the use of fire-fighting foams. As discussed in the market analysis, the main application for PFAS-based fire-fighting foams are class B fires (flammable liquids and gases). Hence, to eliminate the need for fire-fighting foams would (in principle) require stopping the use of flammable liquids or gases, or accepting a situation where fires are less well controlled than at present. While this may be possible in a limited number of specific applications where they are not crucial, it seems unlikely in most cases. The consultation has also not specified any likely other responses than using alternatives. Therefore, no other options are considered.

4.1.3. Fire safety: impacts of technical performance of alternatives

Both scenarios 1 and 2 would lead to a transition to alternative foams. The transition associated with RMO 2 would be faster as existing stock would need to be disposed of at the same time. The key socio-economic issue under both scenarios is the likelihood of fires being extinguished effectively and without delay, compared to the situation using PFAS based foams.

The key issues in the technical feasibility of alternatives are three -fold. First, do the alternatives effectively put out fires so that life, environment and property are not at additional risk? Second, if so, are there delays in the duration over which the alternatives can address these fires, considering the technical ability to deliver greater volumes of foams to the fire? Third, do the alternatives have relevant and reliable safety standards so that downstream users can purchase and use these alternatives with confidence, making allowance for testing in users' specific systems?

This sub-section discusses the difference in the fire safety performance through the use of alternative fire-fighting foams. These effects are quantified where possible, and drawn out qualitatively where not. This section draws directly on the analysis of alternatives (AoA). As in previous sections, whilst the AoA started with a long-list of some 30 alternative foam products, it focussed on a subset of seven judged to be illustrative of the efficacy of these. The evidence below focusses on these specific products but refers to wider evidence where relevant. Table E.2 provides a summary of the key information.

Table E.2 Effectiveness of alternatives – summary

Alternative	Attained performance standards?	Information from 'real world' use	Additional stakeholder information
Respondol ARF 3-6%	Yes - 2 (EN 1568 Parts 3 and 4)	None Identified	Can be used for use in 'all types of flammable liquid fires'.
RE-healing foam RF3X6 ATC	Yes x 4 (EN 1568 Parts 1 and 2, and ICAO Levels B and C))	Yes – Copenhagen Airport & Norwegian Offshore oil sector and Melbourne Fire Brigade.	Has been in used in Municipal Fire Brigade applications – both in training and operational fires.

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RE-healing foam RF1-1%	Yes – 1 (EN 1568 Part 3)	Yes – Norwegian Offshore oil sector.	Consultees state this alternative can be used at offshore oil installations and onshore terminals and refinery.
Moussol FF 3X6 (F-15)	Yes x 5 (DIN EN 1568: Part 3 (Heptane): IIIB/IIID, Part 1: Medium ex. – Part 2: High ex. ICAO Low expansion foam – Level B DIN EN 3 21A).	Yes – Sweden, Heathrow Airport (UK), Norwegian Petrochemical sector.	Has been in use at Heathrow Airport (UK) since 2012. See case study.
Foam Mousse 3% F-15	Yes (x1) (EN 1568 Part 3 heptane)	None identified (but consultation has confirmed this is in use)	Consultees state this alternative is largely used in marine applications and is only used for smaller fires (unsuitable for aviation, for example).
Epocol Premium	Yes x 6 and 1 in progress. EN 1568 - 1: Conform EN 1568 - 2: Conform EN 1568 - 3: 1A / 1A EN 1568 - 4: 1A / 1A Oil industry: LASTFIRE Forest fire standards: CEREN Certificate Certification in progress : UL 162 / GESIP).	None identified (but consultation has confirmed this is in use)	Manufacturer states this alternative can be used in all sectors: airports, marine, military, chemicals, oil and gas, municipal fire fighters and from fixed mobile and CAFs. Hydrocarbon fires, all types of flammable polar solvent liquids Consultees indicated this as a possible substitute for large tank fires, but further testing was necessary.
Orchidex Blue Foam 3x3	Yes x 4 (EN 1568 Parts 3 and 4, Oil industry: LASTFIRE, ICAO Level B))	Yes – German airport are reported to be using the product.	Consultees indicated potential for additional volumes and/or time to suppress fires may occur for some fuel types, but for others, the performance is the same as for PFAS foams.

Effectiveness of foams

The central finding, based on evidence from the analysis of alternatives, the stakeholder consultation and the workshop is that from a technical standpoint, no stakeholder concluded

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that alternatives are not technically feasible, at least for the majority of uses. However, as indicated above, a transition period is required to adapt and test the alternative firefighting foam with firefighting equipment and the firefighters to get trained with them. This is particularly true for the oil, petrochemical and chemical sector which can face fire scenarios for which the alternatives have not yet been proven to be fully effective in real large fire incidents.

As noted in the AoA, in aviation several airports have successfully transitioned, as have Municipal Fire Brigades and companies active in offshore oil and gas operations and the marine sector. Evidence indicates that one segment - liquid fuel fires of large atmospheric storage tanks – is a concern for consultees. Large scale tests for fluorine free foams are ongoing and not yet complete, partly because the scale and cost of these tests. However PFAS-free foams have provided equivalent performance to C6 foams during hydrocarbon tank fires of 15, 60 and 80m diameter (during LASFIRE testing). Performance depends on application rate and equipment, but one stakeholder suggested that there is no real reason why these results cannot be extrapolated to bigger tanks (100m) or bund fires. More testing is required to prove performance of alternatives under some conditions. To date, no real-world examples of a successful transition in installations with large tanks are identified. Consultation has noted that, as such, AFFFs are still used when large fuel areas need to be extinguished quickly or in sprinkler systems.

The available evidence suggests that elsewhere technically feasible fluorine free foams have been developed, are commercially available and have been used to the satisfaction of users.

This transition has not occurred without some technical challenges (and cost) and has required testing in each users' system. Additional volumes of foam, compared to PFAS-based products, have been necessary, but not uniformly. Several users have identified – and overcome – technical issues. These related to temperature tolerance of alternatives and the viscosity of foams. Some changes to foam delivery systems, nozzles and some additional storage capacity has been required.

Speed of fire suppression (making allowance for additional volumes required)

Limited detailed information was obtained on this specific aspect. One respondent highlighted there could be a 5-10% gap in the extinguishing time, but that this "mainly" concerned polar liquids. Other consultees noted that equivalent volumes were required and these yielded equivalent performances, but this was not consistently reported. Others noted additional volumes of fluorine free foams, compared to PFAS based products in at least some applications. Some consultees highlight that this was a particular concern with small extinguishers. Whilst one respondent noted that, in general, fluorine free foams are less flexible for users, because they have less margin for error in the proportioning (i.e. volumes required), in their application type and of ease of use. However, other consultees provided feedback of use in specific applications (aviation), including an example of where a fluorine-free foam worked satisfactorily despite deliberate inappropriate application methods as part of testing procedures.

Standards

The analysis of alternatives (Section E.2) provides a list of specific international compliance standards for the various commercially available products, with more details for each

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shortlisted product above. The underlying study¹⁵⁹ (Appendix 5) provides more detail on each of these standards.

Foams are developed to meet specific standard requirements and it is important to note that tests used for standardisation and certification of PFAS-based foams are not necessarily appropriate for fluorine-free foams. Stakeholders highlighted during the consultation workshop that current testing protocols have often been designed with PFAS-based foams in mind. These testing protocols may not be adequately tailored to reflect the fire-fighting ability of fluorine-free foams, because the same application methods may not always be applied and read-across between different burning fuels may not be straightforward. Therefore, it is inherently challenging to compare the two types purely based on certification. Some fluorine-free foams are however capable of meeting standard firefighting certifications applicable to PFAS-based foams and this has been demonstrated in cases where some airports and municipal fire brigades for example have successfully transitioned to fluorine-free foams.

4.1.4. Use patterns of alternative fire-fighting foams to achieve comparable/acceptable performance

This section discusses the impacts associated with the use patterns of alternative fire-fighting foams and includes discussion on: (a) the quantity of alternative foams needed to achieve either comparable performance or performance that is acceptable from the standpoint of safety to PFAS foams. (b) different specific application methods and equipment used.

a) Quantity of foams needed to achieve comparable/best possible performance

The available evidence does not permit a quantitative estimate for the comparative volumes of fluorine free foams required, for each application and with specific foams. However, the consultation allow a range to be specified. The same approach is used for the availability assessment below. It is important to note that the available quantitative information received – despite extensive attempts for specific information and for clarification – was very limited. Based on the available data, the range specified was between no change in volume and up to a maximum of 100% additional foam required, note the 100% volume estimate was specified by just one consultee and it is understood that this relates to use in one application. The available information is not sufficient to conclude these are isolated cases. As noted in the previous section, this does not apply to liquid fuel fires of large atmospheric storage tanks/large scale tank fires. Here, consultation indicates that large scale testing is still needed to confirm performance.

The details on specific shortlisted products – which are known to be in use within the EU (based on stakeholder consultation) – are set out below.

Table E.3 Use patterns of alternatives – summary

Alternative	Comparative volumes required vs PFAS containing foam
Respondol ARF 3-6%	No specific data has been supplied, despite attempts to obtain this via consultation.
RE-healing foam RF3X6 ATC	Variable depending on application ("drop in replacement, with no additional volumes required in offshore oil installations, onshore terminals and refinery).

¹⁵⁹ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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RE-healing foam RF1-1%	No difference to PFAS based foams (evidence available for some applications only).
Moussol FF 3X6 (F-15)	Volumes vary depending on application. From no difference to up to c. double the volume required in some applications.
FOAMMOUSSE 3% F-15	No information available.
Epocol Premium	Range depending on application. Whilst stakeholder data is limited and relates to just one consultee, the potential ranges specified were between 30 - 50% greater volumes required. It is not clear whether the latter figure is only in exceptional circumstances.
Orchidex BlueFoam 3x3	Consultation data unclear – potential need for up to 10% additional volumes.

b) Specific application method for the foams or equipment used (if different for alternatives compared to PFAS-based foams)

Several respondents report that for fluorine free foams used in sprinkler applications, special sprinkler nozzles have to be installed, which included “special low expansion nozzles”. For extinguishers, consultees noted that greater expansion is required for PFAS free foams. Therefore, depending on the extinguisher, pressure may need to be increased and different nozzles required.

Respondents also referred to challenges associated with temperature tolerance and viscosity of alternative foams. These appeared to have been satisfactorily resolved. Another noted that, as the chemical nature of the fuel varies, more than one agent may need to be stocked by users so that they may be able to deal with fires of different types on any one site. This was reported to be a reflection of a lower level of “flexibility” in fluorine-free foams. This has logistical, training and safety implications for users. The correct foam agents will need to be stocked, in appropriate locations, with ease of access along with processes and training to ensure users cannot use incorrect foam agents, particularly in fast moving emergency situations. Again, further specific information was not available to enable conclusion as to whether this risk applies differently to specific user sectors.

4.1.5. Impacts associated with the economic feasibility of alternatives

This section discusses the economic feasibility of alternatives. There are several elements assessed. First **annual** foam costs – based on the additional volumes required by industry in any one year, this is evaluated based on the price differences between alternative and PFAS-based foams are evaluated, considering whether additional volumes of the alternative are required to fulfil the same/acceptable functionality. So this is in effect, the cost for one annual replacement “cycle” as foams are used and/or disposed of as they pass their useful life. The net change in foam costs is then estimated. This is relevant for both Scenarios. Second, in RMO 2 users would no longer be able to use the **foam stocks they have purchased**. The costs for this stock will have to be written off and new stocks purchased.

A **range of other costs**, associated with testing (and other R&D), storage, technical changes in foam dispensing and/or storage equipment and regulatory approvals are also summarised. The likelihood of whether additional costs would be passed down the supply chain is also considered.

Lastly, costs may be partly offset by **savings of using alternatives**, e.g. from less costly waste management when they reach their expiry date.

The assessment is associated with significant uncertainty and this is reflected in the wide ranges presented. There are uncertainties in several input assumptions, summarised in Table E.4.

Commented [MD63]: Figures will be checked with updated data.

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- Existing use of PFAS based foams is between 14,000 and 20,000 tonnes per year. The best estimate used in the analysis is some 18,000 tonnes per year;
- The average price of existing PFAS-based foam is subject to uncertainty, reflecting the wide range of specific foam compounds used. It is understood that certain compounds are currently available containing high proportions of PFAS and, whilst these are judged to be effective foams, the price for these compounds is well above average, the market assessment noted that these are uncommon. The weighted average used is €3,000 per tonne of PFAS containing foam, as set out in the market assessment. Note the lowest and highest values identified in the market assessment and stakeholder consultation were €2,000 per tonne and up to €30,000 per tonne. The latter figure has a significant effect on the ranges in the socio-economic assessment, but there is insufficient data to conclude the extent of the market currently pay this price per tonne for product;
- Based on these parameters, the current baseline foam costs are somewhere between €28 million per year and a maximum of up to €600 million per year. The best estimate is current costs of €54million per year (i.e. €3,000 multiplied by 18,000 tonnes);
- The same uncertainties apply to the average prices per tonne of fluorine free foams. The market assessment concludes, based on information provided via the stakeholder consultation, that fluorine free foams, on average, are likely to be the same price, i.e. around €3,000 per tonne of foam¹⁶⁰. This value is used in the central estimate. The ranges in the table below are the lowest and highest prices quoted in the consultation, respectively. This indicates that the most expensive fluorine free foam is likely be less expensive than the most expensive current foams. As noted above, this has a significant effect on the result and is subject to particular uncertainty; and
- Finally, consultees noted a range of different volumes may be required to fulfil the same/acceptable functions. The comparative volumes required differed, depending on the specific application and customer need. Therefore, a range has been used, between a 0% increase and up to 100% more fluorine free product, over and above the volumes required for PFAS-based foams.

Costs for one annual cycle of foam replacement (Total EU market)

Table E.4 summarises the assumptions used in the following to estimate annual foam replacement costs.

Table E.4 Annual foam costs – input assumptions

Baseline PFAS foam market t/yr Central (L-H)	Average price €/tonne of foam Weighted average (L-H)	Current foam costs (PFAS) EU market cost per year Best estimate (L-H)	Average price per tonne of foam (Fluorine free alternatives)	Additional volumes required % increase over PFAS based foams) L-M-H
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¹⁶⁰ E.g. Eurofeu indicated in their comment #2983 to the PFHxA restriction that the assumed price level for fluorine-free foam agents of 2,200€/ton might be correct for use in standard applications such as municipal firefighting but that the industrial grade foam agents that would be required for the chemical/petrochemical industry and similar risks are ≥5,000€/ton. Source: Part 2 document available at <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

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18,000 (14,000- 20,000)	€3,000 (€2k-€30k)	€54m (€28m - €600m)	€3,000 (€0.7k-€10k)	0% - 50% - 100%
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Source: Market assessment, desktop research and stakeholder consultation exercise. Note, the maximum baseline used in the SEA is 21,000 tonnes, rather than the 20,000 in the market assessment due to rounding of volumes used at sector level.

Using the assumptions above, Table E.5 sets out the potential costs expected to be incurred by the EU market as a whole through purchasing volumes of fluorine free foam in an annual cycle. Overall, this suggests demand for alternative foams of between 14,000 tonnes per year and up to a maximum of 40,000 tonnes per year, for the sector as a whole. The associated costs are estimated at between €21 million and €30 million per year, with c. €27 million considered to be the most likely average cost for the EU market as a whole. Again, it is recognised that individual companies/users would incur greater or lower costs per tonne and require differing volumes. The wide ranges in different foam costs indicates whilst the average company may experience some increases in costs, others would experience savings, potentially quite large savings for some very specific market segments.

Table E.5 Scenarios, gross and net foam costs –annual cycle replacement costs for total EU market (M denotes millions)

	Costs for existing PFAS based foams (EU Market – best estimate (Range))	Tonnes of alternative required (EU Market) (L-M-H)	Potential foam costs using alternative products (EU Market) Best estimate (Range)	Net change in foam costs (EU market) Best estimate (Range)
Best estimate (assuming 18,000t) PFAS foam use p/yr)	€54m (€36m - €540m)	18,000 - 27,000 - 36,000	€81m (€13m to €360m)	€27m (-€23m to -€180m)
Assuming low PFAS foam use (14,000 t/yr.)	€42m (€28m - €480m)	14,000 -21,000 – 28,000	€63m (€10m - €280m)	€21m (-€18m to -€200 m)
Assuming high PFAS foam use (20,000 t/yr.)	€60m (€40m - €600m)	20,000- 30,000 – 40,000	€90m (€14m- €400m)	€30m (-€26m to -€200 m)

Source: Market assessment, desktop research and stakeholder consultation exercise.

It is important to note that the stakeholder consultation indicated many users had experienced no increase in foams costs and indeed no additional volumes required. The above has been undertaken to assess the potential scale in a best and worst case, using reasonable assumptions in the absence of complete data.

Costs for stock write off and replacement (Total EU market)

In addition to the annual replacement cycle, under RMO 2 the entire stocks of PFAS foam would need to be disposed of and alternative volumes of foam would then need to be purchased. In the baseline, foam stocks would also have to be replaced once they are used or expired, so the restriction would bring the replacement costs forward. To reflect this, the value of the depreciation of stocks at the point of replacement due to the restriction is also considered. Assuming an even age distribution of stocks of PFAS-based foam and a linear

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depreciation of foams over their lifetime, the restriction would cut the life of the foams in half on average, and so half of their original purchase value would already have depreciated and should not be considered as a cost of the restriction. The restriction could also cause additional cost of purchasing alternatives instead of PFAS-based foam taking account of both the price differential and the potential difference in volumes required. As above there is significant uncertainty in the input assumptions and these are presented as a possible range of costs.

Table E.6 Quantitative data - economic costs

Baseline	Existing stocks of PFAS-based foam:	Purchase costs (one-off total for whole stock):	Value of stock depreciated:
	Average: 322,500 (Between 210,000 tonnes and 435,000 tonnes)	Average: €970 million (range €420 million to €13 billion)	Average: €485 mill on (range €210 million to €650 million) (half of purchase cost, assuming even age distribut on and linear depreciation)
Restriction Scenario	Volume of replacement with fluorine-free alternatives:	Purchase costs (one-off total for whole stock) :	Additional cost of the restriction:
	Average: 483,750 (Between 210,000 tonnes and 870,000 tonnes)	Average: €1.5 billion (range €150 million to €9 bill on)	Average: €1.0 billion (range-€60 million - €8.3 billion) (Purchase cost of replacement minus value of existing stock depreciated)

Based on PFAS foam costs of €3,000 per tonne weighted average (with lowest costs of €2,000 and highest of up to €30,000 per tonne) and fluorine-free foam costs of €3,000 per tonne weighted average (with lowest costs of €700 and highest of up to €10,000 per tonne)

The cost of the foam itself are only one aspect of the economic considerations of adopting alternatives. Additional transitional costs are described below. It has not been possible, despite attempts to obtain further quantitative information, to estimate costs for the market as a whole. However, several consultees noted that whilst additional costs were incurred, these were not significant and had proved manageable. Available quantitative information is summarised below. Further information is also presented in the case studies. Note that the cost of disposal of stocks of PFAS foam is covered in a later subsection (I. Costs of disposal of legacy foams).

Table E.7 Quantitative data - economic costs

Testing costs	Storage costs	Costs from technical changes	Other costs including regulatory approvals
No quantitative data has been obtained via stakeholder consultation, despite several requests for such information. Testing would be associated with costs for sample volumes of foam (likely several different products)	Experience in the Norwegian petrochemical sector (Equinor) included additional costs related to purchasing additional volumes of foam, to replace the previous PFAS containing foams, no information was provided on whether there were costs implications related	Consultat on indicated that new nozzles had been required in several cases. Typical costs for a range of firefighting nozzles are within an approximate range of between €5 or less, per piece for simple foam nozzle devices, to c. €30 and up to c.€60 for marine firefighting	Experience in the Norwegian petrochemical sector (Equinor) indicates costs (labour time) in the region of €360,000 for a range of support in their transition at a total of 45 sites (so in the order of c. €10,000 per site). This would therefore appear to be

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Testing costs	Storage costs	Costs from technical changes	Other costs including regulatory approvals
and with staff time and training.	to the need for additional storage space..	nozzles or "heavy duty applicators" and up to c €200 for more specialist equipment [1] Mobile foam units are in the region of €2,700 [2]	an upper bound cost for a company transitioning.

Notes

[1]: Costs derived from search of widely available commercial products. See: https://www.made-in-china.com/products-search/hot-china-products/Water_Foam_Nozzle_Price.html See also: <https://www.orbitalfasteners.co.uk/products/heavy-duty-foam-dispenser-gun> See also: https://www.dortechdirect.co.uk/heavy-duty-pu-applicator-gun-for-expanding-foam.html?oclid=FAIaIOobChMIudKHq9GP5qIVSbDtCh31AATFEAQYASABEql5S_D_BwE See: https://www.safetyshop.com/lever-operated-nozzle-for-fire-hose.html?oclid=FAIaIOobChMI6cKnwNmp5qIVAuDtCh2KMwErEAQYAiABEql91PD_BwE&qclsrc=aw.ds See: https://www.fireprotectiononline.co.uk/hv-series-low-expansion-foam-branch-pipes.html?oclid=FAIaIOobChMIuqgg_Nmp5qIViLbtCh0ImqYXEAQYByABEqlFdvD_BwE
 [2]: https://simplyextinguishers.co.uk/df130-mobile-foam-units.html?oclid=FAIaIOobChMI4vv79vP5qIVapOzCh1-PQghEAKYBiABEql5fD_BwE

Commented [MD64]: See the additions I made below from the PFHxA comments where much larger costs are reported.

Testing costs

Whilst there are several categories of foam designed to address fires from specific fuels, consultation stressed that there are many more different types of overall fire systems, each with slightly different requirements. There is evidence that several downstream users are currently testing fluorine free firefighting foams, and that several others have now successfully transitioned. All stressed the importance of testing the foam compounds. This imposes costs in purchasing (possibly several different types of product), along with storage, training of personnel, performance monitoring and evaluation, disposal and clean-up. Consultees also noted costs from periodic testing of the fluorine-free products once in storage, to ensure that performance is not degraded; this was in the context of some initial uncertainty over shelf life for some products, which now appears to have been addressed. Whilst these costs were acknowledged, the evidence indicates they are one-off, comparatively small and were absorbed by the downstream users.

Storage costs (including storage during transition)

Whilst technical performance of alternatives was concluded to acceptable in most cases, some noted a "higher sensitivity" of fluorine free foam, compared to PFAS based foam; i.e. they allow for less flexibility in use, requiring multiple types of foam to be stocked. This is associated with costs in purchasing foam, of storage capacity – particularly during a transition when both PFAS based and fluorine-free may have to be stored – as well as some training costs. Where evidence has been provided in the stakeholder consultation, it was noted that these costs were manageable and could be mitigated via phased transition. It was acknowledged these costs are generally greater for fixed than for mobile applications, and where larger volume are used and stored.

Costs from technical changes

From an initial survey, no consultees indicated that a transition from PFAS-based foams to fluorine-free required investment in entirely new foam delivery systems. However, problems have been encountered in specific components: such as proportioner pumps, jets and nozzles

Commented [MD65]: @Kalle: I added a few elements on cost of technical changes that you probably need to take into account in the overall cost calculation. Note that this mostly apply to the oil/chemical sector. See also PFHxA comments 2893 and 3146.

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for discharge, including the need for replacement nozzles; including low expansion nozzles. These challenges appear to have been caused by differences in foam viscosity. Typical costs for a range of firefighting nozzles are within an approximate range of between €5 or less per piece for simple foam nozzle devices, to c. €30 and up to c. €60 for marine firefighting nozzles or “heavy duty applicators” and up to c €200 for more specialist equipment¹⁶¹. Mobile foam units are in the region of €2,700.¹⁶²

However, concerning large user sites like oil refineries Eurofeu and the Firefighting Foam Coalition indicated in one of their comments on the PFHxA restriction proposal¹⁶³ that “the cost for handling, cleaning and retrofitting can ramp up to 15-20 Mio € for a single one of Europe’s biggest chemical sites. On average a site operating 20-40 storage tanks require 2-5 Mio. € for retrofitting. Tankterminal.com lists 1,166 tank terminal facilities in Europe operating in total 30,982 tanks. This is per site on average 27 tanks having a total storage capacity of 215,000 m3. It also needs to be considered that any change to the system of a site also triggers additional testing and calibration costs to ensure full functionality.”

From Eurofeu’s contribution the costs of technical changes can be inputable to elements such as the need for increased storage volume of foam concentrate and for the need to retrofit the bund areas in some tank farms to cover a significantly higher volume of liquids, associated with an emergency response action.

Other costs

These include regulatory approvals and those associated with bringing new products to market. Given that the market assessment noted at least some current use of fluorine free products in all sectors, further adopting fluorine-free foams would appear to be a continuity of an existing transition – so a lot of the initial costs associated with new products development will have already been incurred. Experience in the Norwegian petrochemical sector (Equinor) indicates costs (labour time) in the region of €360,000 for a range of support in their transition at a total of 45 sites (so in the order of c. €10,000 per site).

Savings from adoption of fluorine free foam

Many stakeholders acknowledged potential for savings from use of fluorine-free foams. The potential savings resulting from a reduction of firewater that requires disposal and hence the

¹⁶¹ Costs derived from search of widely available commercial products. See: https://www.made-in-china.com/products-search/hot-china-products/Water_Foam_Nozzle_Price.html See also: <https://www.orbitalfasteners.co.uk/products/heavy-duty-foam-dispenser-gun> See also: https://www.dortechdirect.co.uk/heavy-duty-pu-appl-cator-gun-for-expanding-foam.html?gclid=EAIAIQobChMIudKHq9GP5gIVSbDtCh31AATEEAQYASABEgLS5_D_BwE See: https://www.safetystop.com/lever-operated-nozzle-for-fire-hose.html?gclid=EAIAIQobChMI6cKnwNmp5gIVAUdCh2KMwErEAQYAiABEgLS1PD_BwE&gclidsrc=aw.ds See: https://www.fireprotectiononline.co.uk/hv-series-low-expans-on-foam-branch-pipes.html?gclid=EAIAIQobChMItdqg_Nmp5gIViLbtCh0ImgYXEAQYByABEgIFdvD_BwE

¹⁶² https://simplyextinguishers.co.uk/df130-mobile-foam-units.html?gclid=EAIAIQobChMIIn4yv79yP5gIVgpOzCh1-PQghEAKYBiABEgKsIfD_BwE

¹⁶³ Comments #2983 and #3010 to the PFHxA restriction proposal, available in “Part 2” document at Part 2 document available at <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

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costs of disposal as well as from avoided long term liability for site contamination/ remediation and clean-up costs are discussed further in subsection “g. Remediation and clean-up”.

However, fire-fighting foams may also need to be disposed of when not used at the time of their expiry date. As discussed in more detail in Section “j. Emissions from disposal”, incineration is considered the most appropriate disposal option for PFAS-based foams. The disposal method for fluorine-free foam would depend on the hazards of the specific foam. However, in general they are expected to exhibit lower hazards and higher biodegradability, so it is likely that they require less costly disposal methods, such as waste water treatment. While no specific data was available to estimate the disposal cost of fluorine-free foams, the costs of incinerating PFAS-based foams is expected to be typically around €1 per litre (range €0.3 to €11, see Section “l. Costs of disposal” for more detail).

As discussed in the emission assessment (Section B.9.), a number of references suggest usage rates of around 15-20% of existing stocks per annum, with an AFFF shelf-life of up to 15 years, which would suggest all foam concentrate is used before expiration, while other sources suggest that significant quantities of expired foam concentrate is indeed destroyed. If the usage rate of 15-20% per annum of existing stocks is an average across all sectors of use, there will be some installations with potentially far lower usage rates annually that will likely have some foams that reach expiry before use. In the absence of specific data, below the potential costs are shown for 1%, 5% and 20% of annual foam purchases replacing foams that have reached their expiry date¹⁶⁴. Note that these figures are hypothetical and are shown to illustrate the potential order of magnitude only:

Commented [MD66]: To be updated.

Total foam purchased per year (tonnes)	% of annually purchased foam replacing foams not used (hypothetical)	Foam to be disposed of per year (tonnes)	Cost of disposal: €0.3/l (low)	Cost of disposal: €1.0/l (best estimate)	Cost of disposal: €11/l (high)
14,000 (low)	1% (low)	140	42,000	140,000	1,540,000
18,000 (average)	5% (central)	900	270,000	900,000	9,900,000
20,000 (high)	20% (high)	4,000	1,200,000	4,000,000	44,000,000

Sources: Foam tonnage per year based on Eurofeu data (see Annex A), disposal costs per litre based on Section “l. Costs of disposal”.

Based on the total foam purchased per year, foam disposal costs per litre and hypothetical shares of foams not used per year, it is estimated that the annual costs of PFAS-based foam disposal could be between some €40,000 and some €40 million, but more likely (as a central estimate) in the order of million Euros.

Other potential benefits noted by consultees include emerging concerns over corporate reputation from continued use of PFAS foams and savings from avoided cross contamination of other waste streams, from monitoring, environmental permitting requirements, controls and personal protective equipment.

Despite additional stakeholder consultation, and some specific examples of savings, it has not been possible to provide an overall estimate of these savings for the market or average firm. The savings were however noted as “significant” by several consultees.

¹⁶⁴ It is also assumed that all PFAS-based foams are incinerated, although it should be noted that not all PFAS-based foams are currently incinerated when they reach their expiry date (e.g. some of them are used for training), so this is likely an overestimate.

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4.1.6. Environmental/health impacts of alternatives

This section discusses the environmental and health impacts of alternatives to PFAS foams, in comparison with PFAS-based foams. A quantitative comparison of emissions and the associated risk under each scenario was not possible with the available data. The assessment focusses on the overall assessment of hazards (Section B.5) and emissions (Section 1.1.5) alongside an evaluation of the hazards and risks of most likely alternatives.

The evaluation in Section B.5 concluded, based on analysis of PNECs and data on biodegradation and bioaccumulation, that the two fluorinated substances (used as examples) are of higher environmental concern compared to the non-fluorinated substances when it comes to hazard for the environment. This reflects the former's non-biodegradable nature, along with the relatively low PNECs for water and soil. Some of the alternative substances also exhibit low PNECs, but are readily biodegradable. The assessment in Section B.5 notes that further work would be needed to assess the risks associated with specific sites or food production pathways.

Table E.8 provides an overview of the hazards of the shortlisted alternatives based on information from the foam Safety Data Sheets (SDS). None of the components included in the Safety Data Sheets are classified with CMR properties. In terms of PBT/vPvB properties, whilst none of the alternatives include substances *demonstrated* to be PBT or vBvP substances, for two products insufficient data are available and tests had not been concluded for a third. The hazard posed by PFAS foams compared to the constituents of the alternative fluorine-free foams are considered further in B.5. However, a review of potential hazards based on PNECs, biodegradation and bioaccumulation shows that fluorinated substances (in PFAS-based foams) are of higher priority compared to the non-fluorinated substances (in fluorine-free alternatives) when it comes to hazard to environment. This is due to the fact that some PFAS are not readily biodegradable, are mobile and have relatively low PNECs for water and soil. Some of the substances used in the alternative products do however exhibit low PNECs, but this needs to be considered in the context of biodegradation and so far data is not available to examine these in detail.

Commented [MD67]: Add info on high BOD

Table E.8 Overview of key hazards of alternatives based on information from SDS

	CMR Properties	PBT or vBvP Criteria?	Other HH concerns indicated in SDS	Other Env concerns indicated in SDS
Respondol ATF 3-6%	No	No	Skin and serious eye irritation (H315, H319)	None
Re-Healing Foam RF3x6 ATC	No	Uncertain (insufficient data on SDS)	Serious eye irritation (H319)	None
Re-Healing Foam RF1 1%	No	Uncertain (insufficient data on SDS)	Skin irritation and eye damage (H315, H318)	Aquatic Acute 1 (H400)
Moussol FF 3x6 (F-15)	No	No	Serious eye irritation (H319); damage to kidneys if swallowed (H373)	Can harm aquatic fauna, can harm bacteria population in WWT plants
FOAMOUSSE® 3% F-15	No	No	Harmful if swallowed (H302), skin irritation and serious eye irritation (H315, H319)	None
Ecopol Premium	No	No	Serious eye damage (H318)	None
Orchidex BlueFoam 3x3	No	Not tested	Harmful if swallowed (H302) and serious eye irritation (H319)	Harmful to aquatic life with long lasting effects (H412).

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4.1.7. Remediation and clean-up

This section discusses the economic implications in terms of reduced requirements for remediation potentially resulting from a restriction on PFAS-based fire-fighting foams under RMO 1 or 2. Both scenarios will require a transition to alternatives. This means that in both Scenarios, emissions of PFAS related to fire-fighting foam use will cease. In RMO 2 they will cease immediately upon the restriction taking effect, while under RMO 1 further use, emissions and site-contamination could presumably take place. Emissions of the substances used in the alternatives would likely increase proportionately, assuming no additional containment measures compared to the current use of PFAS-based foams.

Commented [MD68]: This section has been complemented with text from Wood's study but not initially present in the Annex XV version of this report.

Definition of “remediation” versus “clean-up”

Remediation

Remediation pertains to legacy contamination that historically occurred from firefighting or training activities using PFAS-based products. Remediation in this sense would only include PFAS-impacted sites because remediation cannot be anticipated at this point for replacement substances (e.g. fluorine-free foams). It is assumed that substances that are of concern for human health and the environment, based on toxicology, fate and transport, or other legal/relevant drivers, will not be used in alternative fluorine-free foam products. As described above the substances contained in fluorine-free alternatives exhibit lower concern than PFAS used in fire-fighting foams, due to their lower hazards and rapid biodegradation. Should fluorine-free foams become a burden in the future, and themselves require soil and/or groundwater remediation beyond the constituents of the fuels that have been extinguished, an evaluation needs to be conducted then. So far, no cases have been identified where remediation has been required due to contamination from fluorine-free alternatives.

In the use scenarios considered in this assessment, typically remediation sites include a soil source zone where the actual fire-fighting activity has been carried out. PFAS compounds present in shallow soils tend to leach with infiltrating precipitation to greater depth in the soil column eventually reaching groundwater. Once groundwater has been impacted, huge dilute plumes tend to form. Groundwater plumes are large because PFAS compounds are very mobile in the subsurface and because of the very low concentration thresholds that are relevant to human health and the environment¹⁶⁵. Contaminated groundwater is in itself a concern since groundwater is a sensitive and important receptor. The critical use of groundwater can include groundwater extraction for drinking water for human consumption, for agricultural irrigation of crops, or for watering of farm animals. Groundwater can also become – directly or indirectly – surface water by extraction and surface discharge or by groundwater/surface water interaction in rivers, streams or lakes.

Typically, remedial activities are driven by regulatory processes and include the use of remediation target levels or follow a risk-based approach. The number of PFAS compounds that currently “drive the market” are few in comparison to the number of potential PFAS compounds known and likely present at a remediation site. At the same time, there are only a few PFAS compounds that are in the centre of attention based on the magnitude of their production and use, here for AFFF products. As a consequence, the number of PFAS compounds that have been researched with respect to their toxicology, fate and transport in the environment, and effects on human health and the environment is relatively small. Only about a couple dozen individual compounds have been sufficiently studied. In many European countries, there are only a few PFAS compounds that are regulated with respect to their

¹⁶⁵ ITRC Fact Sheet; Environmental Fate and Transport for Per- and Polyfluoroalkyl Substances, March 2018.

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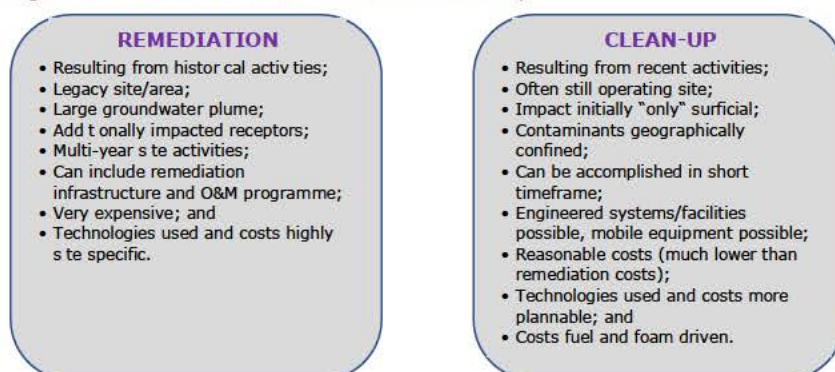
allowable concentrations in drinking water, ground water, surface water and soil¹⁶⁶. In December 2019, the European Commission and European Council agreed to set parameters for PFAS under the Drinking Water Directive (98/83/EC). Member States will be able to choose either a parameter of 0.1 µg/l for the sum of PFAS listed in Annex III of the Directive, or of 0.5 µg/l for the totality of PFAS once technical guidelines for monitoring this parameter are developed. To address concerns related to groundwater, a pilot exercise was launched in 2017 which resulted in ten PFAS being added to a “list facilitating Annex I and II review” (a list of possible substances to be considered for additional regulation in the future review of the Groundwater Directive annexes) and two PFAS to be added to a first voluntary watch list.

Clean-up

Clean-up relates to new incidents or accidents such as planned training activities or emergency response actions, respectively. Currently, it should be assumed that training activities with PFAS-containing foams are largely conducted at fully contained training facilities so that fire-fighting water can be completely captured and addressed with thorough treatment, as discussed above. However, there might be exceptions where release to the environment from training occurs, and there are still emergency responses where PFAS-based foams are used. Clean-up of an emergency response site would need to happen as soon as possible after the fire is controlled and the site is safe to enter to reduce the potential or the amount of PFAS able to infiltrate into the soil matrix. Environmental sampling from affected soil and/or water (surface water and/or groundwater) might need to occur to determine follow-on actions to remove unacceptable concentrations.

The potential processes and technologies used for remediation and clean-up are discussed further in Wood, 2020¹⁶⁷.

Figure 6.1 Overview of “Remediation” vs. “Clean-up”



¹⁶⁶ Concawe Report, Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS), June 2016.

¹⁶⁷ See section “Step 5 - Treatment technologies and treatment scenarios – soil and water” in (Wood 2020)

Contamination scenarios: PFAS-containing foams and fluorine-free foams

PFAS-containing foams

For PFAS-containing foams at legacy sites, contamination patterns normally include soil, both unsaturated and saturated, to be impacted by PFAS at higher concentrations, because the PFAS entry point into the subsurface occurs from above ground in most scenarios, specifically for fire-fighting and training events. PFAS leaching to greater depths in the soil column by infiltrating precipitation eventually reaching groundwater is commonly observed at legacy sites. Leaching is supported by the physicochemical characteristics of PFAS. PFAS in shallow soils can also be transported via overland flow by storm water run-off during precipitation events. Storm water would either infiltrate into the ground at an area geographically separated from the original fire-fighting activities, or storm water run-off can directly discharge to a surface water body such as a river, stream, or lake, or it can be captured in a storm-/ waste water treatment facility. Historically, storm- or waste water facilities were not required to analyse for PFAS compounds. It can be assumed that most PFAS have passed untreated through a treatment works without awareness of the operator allowing for PFAS to spread to the wider environment¹⁶⁸.

The PFAS-laden soils in the source area continue to be an emission source for groundwater contamination for many years, if not decades. Once PFAS-compounds have reached the aquifer or a water-bearing unit, those compounds tend to migrate laterally and in a hydraulically downgradient direction with limited retardation from the soil matrix and negligible, if at all occurring, breakdown through biotic or abiotic processes in the aquifer¹⁶⁹. As a consequence, PFAS tend to generate large plumes in groundwater. Acceptable PFAS threshold concentrations are extremely low, and plumes can be many kilometres long. In the Veneto region, Italy, a PFAS-production facility contaminated an area spanning more than 200 square km¹⁷⁰. Various scenarios can result from PFAS-impacted groundwater. Groundwater could be extracted and used as drinking water. Extracted groundwater could also be used for irrigation of agricultural land. In addition to soil and groundwater impacts, surface water could be impacted from historically contaminated soils by means of surface water run-off. Under certain hydrogeological conditions, groundwater can become surface water or interact with surface water in brooks, creeks, streams, or river beds. PFAS-contaminated surface water is a major concern under the Water Framework Directive with an extremely low Environmental Quality Standard (EQS) for PFOS (annual average EQS for PFOS is 0.65 ng/l)¹⁷¹. PFAS-impacted ground or surface water can become a challenge when they enter a water treatment works at privately owned locations (e.g. oil and gas sites or airports) or public treatment works, as indicated above. In most cases PFAS are not analysed for in water treatment works and the presence or absence of PFAS are consequentially unknown. PFAS would require in most, if not all, cases, a separate treatment step in the water treatment works with potential requirements for additional pre-treatment (e.g. high dissolved organic carbon (DOC) can be a problem in treating PFAS) and retrofitting of the treatment works at a substantial cost.

¹⁶⁸ Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.

¹⁶⁹ Concawe Report, Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS), June 2016.

¹⁷⁰ World Health Organization, Keeping our water clean: the case of water contamination in the Veneto Region, Italy, 2016.

¹⁷¹ Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.

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Fluorine-free foams

Based on the definition of “remediation” and “clean-up” there would not be a remediation scenario that includes fluorine-free foam compounds as of now. For one, replacement products are fairly new to the market and possible/potential impacts from fluorine-free foams to the wider environment has not yet caused adverse effects. The current expectation is that replacement products (alternatives to PFAS-based foams) do not have the potential to contaminate soil and/or groundwater in a way that remediation can be assumed or predicted to be needed. The analysis of alternatives has shown that the substances contained in shortlisted fluorine-free alternatives (i.e. a set of alternatives considered likely to be used) exhibit lower hazards than PFAS and rapid biodegradation. Even if those alternative substances have the potential to contaminate soil and groundwater, remediation scenarios/technologies are hard to define. Remediation in most EU countries is risk-driven. That risk from alternative products cannot reasonably be anticipated at this point to develop a “remediation scenario” including treatment technologies and associated costs.

There was anecdotal evidence presented by one stakeholder that fluorine-free foam caused emulsification of the run-off water in a water treatment works. Should emulsification be a recurring issue for use of fluorine-free foams, then a separate treatment step to break up the emulsion would need to be included at the water treatment works as a retrofit at an additional cost.

Also, an anecdotal example was presented from another stakeholder that a permit was granted where 5000 litres of firewater runoff from fluorine-free foams could be discharged directly to a sewer after “only” a fuel separator step.

Point of treatment – source area, site hydraulic control, plume, and “end-of-pipe”

As described previously under fire-fighting scenarios using PFAS-containing products, PFAS compounds experience a fate and transport that can be generalised for most occurrences and described as follows (see figure¹⁷² below).

At the location of the active fire-fighting activity PFAS-laden waters enter the subsurface resulting in PFAS-impacted soils – the source area (No. 1). The source area typically holds the greatest PFAS mass. Precipitation supports leaching of PFAS compounds in the unsaturated soil column to greater depth (No. 2) in the soil column eventually reaching groundwater which is then the starting point of a PFAS plume in groundwater (No. 3). Depending on the fuel that was extinguished, PFAS have a tendency to accumulate with free phase products¹⁷³ at the water table intersection. The plume will extend in the direction of and grow with groundwater flow as more PFAS-mass leaches from the source area. Eventually the plume might grow to a size extending past the property boundary (airport, O&G refinery, etc.) migrating off-site. The PFAS plume size might have grown in size and extended into areas where groundwater extraction could occur for domestic (No. 9), commercial or public use (No. 10) including private drinking water wells, agricultural irrigation and livestock feeds, and drinking water production facilities. Stormwater runoff from a fire training area or live fire incident can migrate in various directions predominantly following land surface morphology (No. 5). In consequence, surface water runoff can spread PFAS contamination in directions beyond groundwater flow. Stormwater runoff can directly or indirectly occur via some sort of controlled or uncontrolled overland flow or through underground utilities. Damaged/leaking utility structures can be locations where PFAS could enter the subsurface at a point that is in only limited relation to the actual firefighting area. Stormwater or surface

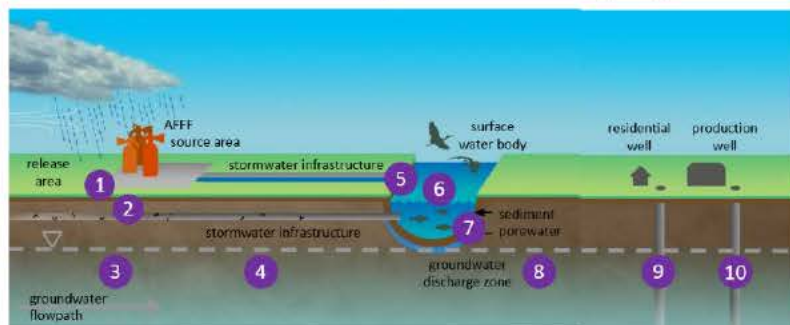
¹⁷² Wood E&I Solutions, 2017.

¹⁷³ Common petroleum hydrocarbon-based fuels are lighter than water (light non-aqueous phase liquids – LNAPL) and accumulate at the water table intersection when they are released to the environment at large enough quantities. “Free phase” refers to a fuel layer on the groundwater table.

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runoff could eventually discharge to a surface water body such as the sea, a lake or pond, or a stream, river, creek or brook (No. 6). Sediments at the bottom of surface water structures including the surface water runoff ditches, drains, channels, ponds, lakes, or the sea can have PFAS-laden sediments as precipitated solids as part of the surface water feature (No. 7).

Figure 6.2 Overview of PFAS fate and transport from use of fire-fighting foams



- | | | |
|--------------------------------|--|----------------------------------|
| 1. Surface soil | 5. Stormwater infrastructure containment | 9. Residential well GW treatment |
| 2. Subsurface soil | 6. Surface water | 10. Production well GW treatment |
| 3. Source area GW | 7. Sediment | |
| 4. Downgradient GW containment | 8. Offsite GW impacted by surface water | |

The point of treatment can be selected based on economic considerations. The investment in Euros spent per mass unit of PFAS removed is largest in the source area (No. 1). The absolute PFAS mass removed is greater in the source area when comparing to groundwater extraction and subsequent treatment. Also, PFAS mass removed in the source area will not be available to support plume growth in groundwater. The point of treatment can also be based to protect a sensitive receptor such as a drinking water (domestic No. 9, commercial, or public No. 10). Here an end-of-pipe technology would treat the PFAS-impacted and extracted groundwater to acceptable levels prior to use or distribution. Hydraulic control of a site could be critical to prevent contaminants to extend beyond the property boundary (No. 4). A series of extraction wells or a drainage wall/trench near the property boundary would ensure that PFAS-impacted groundwater does not extend beyond the property boundary by groundwater flow. The extraction well gallery or drainage would need to be installed perpendicular (as far as possible) to the groundwater flow direction and be long enough to cover the plume width. In most, if not all, cases, remediation of an entire PFAS-plume in groundwater is economically not viable since PFAS plumes are extremely large and, in comparison to other contaminants such as hydrocarbons or chlorinated solvents, they are a concern at very low concentrations.

Source area treatment: Unsaturated and saturated soils are typically treated/remediated by means of excavation and disposal / incineration. Here the largest PFAS mass is typically removed from the subsurface in a short amount of time with a high effectivity, efficiency and potentially long-lasting reduced environmental impact (depending on the end disposal route, e.g. if the leachate from the landfill is correctly collected and treated or if the incineration uses temperatures high enough to reliably destroy PFAS).

Hydraulic site control: To eliminate off-site migration of PFAS-contaminated groundwater, impacted groundwater is extracted at the site boundary through one or more extraction wells or a drainage structure. The extraction process eliminates or greatly reduces the mass flux across the property line. While the hydraulic containment system is not able to recover PFAS-impacted groundwater that has already migrated to off-site areas, it can greatly reduce the potential impact on receptors that could be downgradient, including neighbouring properties

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or sensitive points of use such as private or public drinking water wells or agricultural use wells or surface water structures.

“End-of-pipe” treatment: In the event that PFAS contaminated groundwater is extracted for human use or consumption or for agricultural use, groundwater would need to be treated after extraction. Commercially available treatment technologies to recover PFAS molecules from water include adsorption technologies such as granular activated carbon (GAC) or resins (regenerable and non-regenerable). Reverse osmosis can also be used to treat extracted groundwater.

Short-chain PFAS can be more resilient to some of these treatment technologies, so that more rigorous measures are required for effective treatment (e.g. a secondary treatment step using a resin that is optimised to retain the specific short-chain PFAS compounds, or higher temperature incineration). This is discussed in more detail in Step 5 on treatment technologies.

Drivers for active measures – why is clean-up / remediation required?

For PFAS-containing foams, specifically at legacy sites with historical releases/impacts, remediation is warranted and likely required by regulatory agencies when sensitive receptors (including groundwater) are threatened or already impacted. Guidance levels for up to a dozen or so individually identified PFAS compounds (including PFOS, PFOA, PFHxS, etc.) have been developed in various European countries^{174,175} and parameters for the sum of certain listed PFAS (0.1 µg/l) for the totality of PFAS (0.5 µg/l, once technical guidelines for monitoring this parameter are developed) have been developed for the Drinking Water Directive. For legacy sites in various European countries a risk-based remediation approach would be implemented by describing the risk to relevant receptors based on analytical data collected from environmental media such as soil, surface water and/or groundwater. In some instances, animal/fish or vegetation samples are collected and analysed to evaluate PFAS migration in the food chain at different trophic levels. If a risk to a receptor is not acceptable, active measures would need to be initiated. The level of effort related to an active measure and the measure or combination of measures itself is highly site specific and depends on the level of impact to the site and the sensitivity of the impacted or threatened receptor, amongst other drivers. Case studies on “contamination from use of aqueous film-forming foams” are presented in the report of Nordic Council of Ministers¹⁷⁶ and summarised in the table below.

Table 6.9 Nordic Council report case studies of PFAS contamination from AFFF use

Site	Contamination	Contamination source	Remediation cost
Kallinge-Ronneby Military and Civilian Airbase, Sweden	Detected PFAS contamination in the outgoing water from one of two municipal waterworks which supplied water to around 5,000 people. PFHxS, PFOA and PFOS were sometimes 100–300 higher in the contaminated water source (e.g. up to 8,000 ng/l for PFOS). Blood samples showed significant human exposure via drinking water.	The source of the contamination was identified as the fire drill site located in the nearby military airport where AFFF containing PFOS had been used since the 1980s, then other PFAS-based AFFF since 2003 and fluorine-free foams since 2011.	The cost of changing the water supply from Brantafors to Karlsnäs is estimated SEK 60 million (EUR 5.8 million). The additional annual cost for monitoring is calculated to around SEK 50,000 (EUR 4,800). Significant water resources remain unusable for an unforeseeable

Commented [MD69]: I added this column with costs, coming for the Nordic Council Report.

¹⁷⁴ Concawe Report, Environmental fate and effects of poly- and perfluoroalkyl substances (PFAS), June 2016.

¹⁷⁵ NICOLE, PFASs Summary, January 2016.

¹⁷⁶ Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.

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Site	Contamination	Contamination source	Remediation cost
			future due to PFAS contamination. The loss of these valuable resources has not been monetised.
Jersey Airport, Islands	Civilian Channel 78 properties were within the plume area. Groundwater in 36 of these properties tested positive for PFOS. Although at some of the sites, concentrations of PFOS have shown signs of decline, they have remained at high levels for seven years in private wells (up to 98,000 ng/l).	The airport's fire-training site was identified as the origin of the contamination. In 1991, the fire training site started using AFFFs to meet the requirements of UK Airport Fire Services. The foam used at the site during training exercises was discharged regularly without monitoring, dissolving into the ground and rainwaters. Contamination subsequently found its way into the aquifer and bay.	Long-term remediation works began in 2002 and finished in 2004 with the aim of addressing the current contamination and preventing future problems. The total cost was GBP 7.4 mill on (EUR 10.6 million).
Schiphol Airport, The Netherlands	In July 2008, an error in the sprinkler-system at a hangar released 10,000 litres of AFFF, containing 143 kg of PFOS, into the surrounding environment. This fed into a larger reserve of waste water (100 million litres) kept in five reserve reservoirs, several of which leaked and caused substantial contamination of the soil and surface water. The water resources were found to contain over 12 times the average amount of PFOS otherwise found in several reference sites in the Netherlands.		Contaminated soil from this incident also resulted in delays of over a year to a project to build a new bus lane in Schiphol-Oost in 2017. Over 50,000 m ³ of the soil dug up was found to be contaminated and thus difficult to dispose. The cost of the remediation is estimated at EUR 30–40 million.

Source: Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.

In 2019, reports for the Norwegian Environment Agency's on the PFAS contamination at Avinor's airports were published¹⁷⁷. The study included 39 airports with a total of 59 sites examined for PFAS at these airports. PFOS was detected at almost all airport fire training sites. A total of 32 sites have a calculated amount of PFOS in the ground ranging from 0.5 to 81 kg per site. The total calculated volume of PFOS for these 32 sites is approximately 314 kg (estimated range between 130 kg to 800 kg). Environmental risk assessment have been performed based on the risk associated with the calculated leaching of PFOS/ΣPFAS from contaminated sites/fire training sites, and the existing load in the biota (biota surveys). Vulnerability was assessed as the likelihood of the contamination (PFOS/ΣPFAS) reaching registered drinking water sources, vulnerable nature, or areas for recreation and business interests. Based on this assessment, certain sites have been remediated with techniques depending on the site conditions. Measured concentrations of ΣPFAS in groundwater varied between 275 ng/L and 1,450,000 ng/L depending on the site and time of sampling. The sites

¹⁷⁷ Reporting for Part 1 and Part 2 of the Norwegian Environment Agency's orders: "Overall assessment of PFAS contamination at Avinor's airports", Norconsult, 2019, available at: <https://avinor.no/globalassets/konsem/miljo-oq-samfunn/pfos/rapporter/reporting-for-part-1-and-part-2-overall-assessment-including-appendices.pdf> and Reporting for Part 3 of the Norwegian Environment Agency's orders: "Overall assessment of PFAS contamination at Avinor's airports", Norconsult, 2019, available at: <https://avinor.no/globalassets/konsem/miljo-oq-samfunn/pfos/rapporter/reporting-for-part-3-assessment-of-local-impacts.pdf> (source: <https://avinor.no/en/corporate/community-and-environment/pfos-i-fokus/samlede-vurderinger>)

Commented [MD69]: I added this column with costs, coming for the Nordic Council Report.

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with the lowest cost per kg of PFOS/ΣPFAS removed, was calculated at 7.3 MNOK, with a cost per kg ΣPFAS removed of NOK 357,000. Another site with the largest volume of PFOS/ΣPFAS removed (96 kg) of all, and due to a relatively large volume of masses (22 000 m³) the total cost of remedial action was 51 MNOK, with a calculated cost per kg of the sum of PFAS removed at NOK 533,000.

Clean-up is driven to a large degree by the flammable liquid itself, the soot, water and “dirt” in general terms that contribute to the fire-fighting water runoff and its potential to impact the environment. The foam used might just be another component that will need to be captured and treated, specifically under the scenario of a fluorine-free foam use. As discussed above, it is assumed that fluorine-free foams will not be persistent, mobile and toxic at levels that will require remediation (e.g. legacy site) when they enter the environment. For training activities facilities including the associated water treatment works should be engineered to account for 100% collection of all fluids including fuel and foams that the fire training water can be cleaned and treated accordingly before releasing treated waters back to the larger environment. Should a fire have been extinguished during training or a live event using PFAS-based foam then it is advisable to clean-up the firefighting water promptly after the incident. Depending on the location of a live fire and the foam used, soil samples should be collected from areas where fire water runoff could have percolated into the subsurface to evaluate the presence or absence of PFAS compounds and their concentrations. Depending on the soil analytical results a need for soil exchange might be indicated. After a live fire event, regulatory communication and agreement is required for subsequent steps in the clean-up procedure to reach acceptable site conditions that will not create or leave a risk to human health or the environment.

One stakeholder shared a scenario where clean-up seemed to be challenging. Fire-fighting activities in close vicinity to open water bodies (such as sea or lake) make it close to impossible to recover fire-fighting water runoff discharged into the sea or lake. To avoid runoff entering the sea, engineering solutions would be required as much as that is possible. For facilities in close proximity to large water bodies, one could possibly design berms and a drainage system to recover fire-fighting water in case a fire should truly occur. However, it might also be prudent to switch to less environmentally critical, fluorine-free, foams.

Cost of remediation

The study underlying this restriction proposal¹⁷⁸ (Section 6) has assessed the typical costs of remediation of PFAS contamination resulting from the use of fire-fighting foams. The results are summarised in the table below. This shows that the typical costs per site can range from around half a million Euros (only soil remediation required, lower estimate) to just over €100 million (sum of soil excavation and incineration, groundwater pump and treat and drinking water reverse osmosis, higher estimates).¹⁷⁹

Table E.10 Typical cost per site of remediation of PFAS contamination resulting from the use of fire-fighting foams

Compartment	Technique	Cost

¹⁷⁸ Wood, Ramboll, COWI: “The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report”. Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

¹⁷⁹ Please note remediation costs are highly site-specific and in certain cases can exceed the ranges provided. The estimates should therefore be considered order-of-magnitude cost ranges.

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Soil	Excavation and off-site disposal	€ 0.5 – 18 million
	Excavation and incineration	€ 2.5 – 38 million
	Capping	€ 0.42 - 4.3 million
Groundwater	Pump and treat	€1.2 – 30.3 million
Drinking water	Reverse osmosis	€2.9 – 39.8 million

Source: Wood 2019

Section B.9. has shown that the substances contained in fluorine-free alternatives exhibit lower concern than PFAS used in fire-fighting foams, due to their lower hazards and more rapid biodegradation. On this basis, underlying study¹⁸⁰ (Section 6) has concluded that it is currently not predicted as likely that remediation will be required as a result of the use of fluorine-free alternatives. Therefore, no remediation costs are expected to be incurred from the use of fluorine-free alternatives, implying potential savings from substitution of PFAS-based foams.

It is important to note that the costs refer to the remediation of legacy contamination that occurred from historical fire-fighting and/or training activities. In particular, training activities, which account for the majority of fire-fighting foam use, either already avoid the use of PFAS-containing foams and/or are conducted at contained training facilities, according to current best practice. However, the consultation did not yield information on the extent to which best practice measures are being implemented, or their effectiveness. Section B.9. has estimated that the current levels of emissions from training are likely relatively low; however historical emissions are understood to have been much higher.

Fire-fighting activities typically require more immediate clean-up (discussed further in the next paragraph) rather than long-term PFAS remediation. On this basis, it seems unlikely that the current use of PFAS-containing fire-fighting foams would lead to the same remediation costs as presented for legacy contamination above. In conclusion, the restriction scenarios could eliminate the potential risk of PFAS contamination which could cause costs of up to around €100 million per site.

For European sites the Nordic Council of Ministers report¹⁸¹ describes remediation costs associated with contamination from PFAS ranging from several hundred thousand up to €40 million with one high-cost example for the Dusseldorf Airport, Germany estimating a total remediation cost of up to €100 million. In comparison to the costs provided in this report with the Nordic report remediation costs for PFAS-impacted sites (such as airports) will total from the single digit € millions to the lower double-digit € millions. For Schiphol Airport 50 000 m³ of impacted soil were removed at a cost of €600-800/m³.

As described in previous sections there is a variability in costs for soil remediation depending on factors such as amount of PFAS spilled, presence of other contaminants, the volume of soil that has been contaminated, the type of soil, the environmental setting of the impacted site, and the receptors impacted or threatened.

In the Nordic report cost ranges are given for three airports where costs were modelled. The modelled costs included both water and soil remediation using different methods and different levels of allowable remaining concentrations. The modelled cost ranges spanned from €2.1-24 million (Kristiansand Airport) over €0.4-7.1 million (Harstad/Narvik Airport) to €0.41-8.1

¹⁸⁰ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

¹⁸¹ Nordic Council of Ministers, The Cost of Inaction – A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS, 2019.

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million (Svalbard Longyearbyen). While the remediation technologies were not reflected in the Nordic report those costs are consistent with the estimated cost range as developed in this report

There are large uncertainties in the numbers of sites that may require remediation and remediation costs are very case-specific and would differ significantly across these sites, so the following estimate of total remediation costs caused by the use of PFAS-based fire-fighting foams is indicative only:

- The market analysis (see Annex A) estimated that there are likely to be several tens or potentially hundreds of thousands of sites that use or at least possess fire-fighting foams;
- If all of these would require remediation (costing some €10s of million per site), the costs of cleaning could be at most in the region of trillions of Euros (based on an assumed 100,000 sites needing remediation);
- However, in reality only a much smaller number of these sites would use PFAS-based foams in sufficient quantities and without adequate containment and immediate clean-up to require large scale remediation. More information on the total number of sites, real-world use of PFAS per site as well as implementation and effectiveness of best practices in terms of containment and immediate clean-up would be required to assess to which extent remediation is likely to be required in the future as a result of current use of PFAS-based fire-fighting foams; and
- Therefore, realistically avoided remediation costs are more likely in the order of magnitude of hundreds of millions of Euros (assuming tens of sites requiring remediation at tens of millions of Euros per site) to billions of Euros (assuming hundreds of sites requiring remediation at tens of millions of Euros per site).

Cost of clean-up

In addition to remediation which is driven by long-term accumulated contamination from historical releases, releases to the environment in the short-term require “clean-up”. According to the stakeholder consultation, there is local or national-level regulation governing the containment or prevention of release of fire-fighting foam or firewater runoff to the environment¹⁸². One exception that has been identified is fire-fighting activities in close vicinity to open water bodies (sea, lake), where it is very difficult to recover fire-fighting water runoff discharged into the sea or lake. In the case of the lake, this could lead to remediation being required. This would relate to very specific sites in specific locations, so it would not be appropriate to estimate ‘typical’ remediation or clean-up costs. In the case of the sea (particularly relevant for marine and offshore applications), remediation or clean-up would likely not be feasible, which raises particular concerns over the environmental impact of using PFAS-based fire-fighting foams in these applications. In all other applications, it is assumed that in most cases, the majority of fire-water run-off is contained and sent for treatment. Treatment costs for run-off can vary depending on the fire-fighting foam used:

- Several stakeholders that have transitioned to fluorine-free foam reported that when fluorine-free foam was used, run-off was sent to water treatment, either through the normal sewer system to the municipal WWTPs; directly to on-site waste water treatment; to other biological/chemical/mechanical

¹⁸² This was confirmed by stakeholders at least for England/Wales (The Environmental Permitting (England and Wales) Regulations 2010 (EPR 2010)), Sweden (local authority requirements for applications for new operation licenses), France (no details provided), Netherlands (no details provided), Germany (“Löschwasser-Rückhalte-Richtlinie” and the more detailed Bavarian “Guideline foam” which is legally binding in Bavaria and but also applied elsewhere).

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treatment plants; or even drained directly to sea. One stakeholder reported that all PFAS-containing run off must be treated as a regulated waste which they do using high-temperature incineration;

- Stakeholders did not provide information on the cost of waste water treatment. These can vary significantly, depending on the contamination of the run-off from the flammable liquid itself, the soot and other contaminants from the fire site. For instance, UNECE 2017¹⁸³ reports a cost of €1 million for disposal of 2,000 m³ of firewater contaminated with chemicals in a sewage treatment plant and several chemicals waste disposal facilities, resulting from a fire in a factory in Germany in 2005. This is equivalent to €0.5 per litre, or €0.64 per litre in 2019 prices¹⁸⁴. Typical costs for regular municipal waste water treatment are much lower, for instance reported in the range of €0.0002 to €0.0005 per litre by Pajares et al. 2019¹⁸⁵ for various municipalities in Southern Europe. Hence, treatment costs for run-off for fluorine-free foam are likely between €0.0002 per litre and around €0.64 per litre. €0.3 per litre is assumed as an average for the purpose of the approximate estimation below;
- Assuming that PFAS-containing run-off has to be incinerated, and assuming similar incineration costs as reported for the disposal of fire-fighting foams (see Section "I. Costs of disposal"), the costs for treatment of PFAS-containing fire-water run-off could be around €1 per litre (range €0.3 to €11 per litre). Hence, treatment costs for run-off of fluorine-free foams could be around €0.7 per litre (range ca €0-€11) lower compared to PFAS-based foams¹⁸⁶; and
- Data on the total amount of fire-water run-off containing fire-fighting foam per year in the EU was not available, but for illustration an example of costs per incident can be calculated. UNECE 2017¹⁸⁷ reports five major fire-incidents in which volumes of fire-water used ranged between 2,200 and 38,000 m³. For incidents of this size, the difference in run-off treatment cost would be around €1.5-27 million (range €0-418 million) per incident¹⁸⁸.

¹⁸³

https://www.unece.org/fileadmin/DAM/env/documents/2017/TEIA/JEG_MTGS/UNECE_Safety_Guidelines_and_Good_Practices_for_Fire-water_Retention_14_Nov_2017_clean.pdf

¹⁸⁴ 2005 value converted to 2019 prices using Eurostat: HICP (2015 = 100) - annual data (average index and rate of change) (prc_hicp_a.ind).

¹⁸⁵ Moral Pajares, E., Gallego Valero, L., & Román Sánchez, I. M. (2019). Cost of urban wastewater treatment and ecotaxes: Evidence from municipalities in southern Europe. *Water*, 11(3), 423.

¹⁸⁶ Calculated as:

- Central estimate: €1/l cost of incineration of PFAS-based foams minus €0.3/l cost of waste water treatment for fluorine-free alternatives = €0.7/l cost saving;
- Low estimate: Waste water treatment could in some cases be more expensive (up to €0.64/l) than incineration (from €0.3/l). In these cases it is assumed that the less expensive option would be chosen and there would not be a saving of using fluorine-free foams compared to PFAS-based foams; and
- High estimate: The maximum possible difference is in case of the upper end of the range of incineration costs for PFAS-based foams (€11/l) minus the lower end of the range of waste water treatment costs for fluorine-free alternatives (€0.0002/l) = €11/l cost saving.

¹⁸⁷

https://www.unece.org/fileadmin/DAM/env/documents/2017/TEIA/JEG_MTGS/UNECE_Safety_Guidelines_and_Good_Practices_for_Fire-water_Retention_14_Nov_2017_clean.pdf

¹⁸⁸ Calculated as: 2,200 m³ volume of fire-water run-off * €0.7/l treatment cost difference= €1.54 million. 38,000 m³ volume of fire-water run-off * €0.7/l treatment cost difference= €26.6 million. These figures are rounded to two significant figures. For the wider range, instead of €0.7/l treatment cost difference, €0/l (lower) and €11/l (higher) have been applied.

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In cases where fire-water run-off is not contained and further clean-up is possible (i.e. run-off was not discharged to sea), there may be savings from using fluorine-free foams in terms of reduced clean-up costs:

- When PFAS-based foam is used and contamination of the soil and water occurs then extremely persistent chemicals are involved, which is not necessarily the case with fluorine-free foams. Stakeholders suggested in the consultation that clean-up and complex treatment is not always necessary after the use of fluorine-free foams. This could lead to potential cost savings in some cases;
- However, the underlying study¹⁸⁹ (Section 6) clean-up is driven to a large degree by the flammable liquid itself, the soot, water and “dirt” in general terms that contribute to the fire-fighting water runoff, rather than the fire-fighting foams. Therefore, a significant difference in clean-up costs between the different types of foam used is difficult to estimate, because the incremental costs of addressing PFAS contamination is difficult to separate from the wider clean-up costs; and
- Clean-up costs are generally expected to be lower than remediation costs. Based on the estimates of remediation cost per site presented above, as a worst case scenario, clean-up costs can be expected to be a few hundred thousand to a few million Euros per incident. In the absence of more specific data, for illustration of the potential order of magnitude of savings: Assuming several tens of incidents per year using PFAS-based foams where clean-up is required and could be avoided if fluorine-free foams were used, the savings would be in the order of several millions to several tens of millions of Euros.

4.1.8. Availability of alternatives.

This section discusses the supply-demand balance associated with a restriction on PFAS firefighting foams under RMO 1 and 2. Both scenarios will require a transition to alternatives – the difference is the speed at which this will be necessary. RMO 1 will result in a slower increase in demand as stocks are used in training and or incidents (or reach the end of their useful life) and are then replaced with new alternatives. RMO 2 will result a more sudden increase in demand as the whole market disposes of and replaces their existing stocks – potentially over a short timescale – and then require replacement stock, each year.

In addition, and over and above the replacement demand, it can be assumed both scenarios will result in an increased short-term demand for testing; again the increase in demand would be greater in RMO 2 given the accelerated transition.

The economic and logistical challenges of managing the transition – avoiding contamination in storage tanks and the requirements for disposal, for example – are discussed elsewhere in the SEA. Information on the specific shortlisted substances in the analysis of alternatives is summarised below – quantitative information is limited. These substances are however, illustrative and a subset of a larger range of alternative foams that are commercially available and currently in use.

¹⁸⁹ Wood, Ramboll, COWI: “The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report”. Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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Table E.11 Availability of alternatives – summary

Alternative	Produced in the EU	Currently commercially available	Information on production volumes
Respondol ARF 3-6%	Unknown	Yes	Not available. Stakeholders have indicated that they would not have a problem meeting increased demand in general terms.
RE-healing foam RF3X6 ATC	Yes	Yes	As above.
RE-healing foam RF1-1%	Yes	Yes	As above.
Moussol FF 3X6 (F-15)	Yes	Yes	As above.
FoamMousse 3% F-15	Yes	Yes	As above.
Epocol Premium	Yes	Yes	700 tonnes (product on and import), 500 sold in EU.
Orchidex BlueFoam (3x3)	Yes	Yes	Stakeholder (not manufacturer estimates at c.800 t/yr)

Source: Market assessment, desktop research and stakeholder consultation exercise.

Stakeholder consultation has provided limited information on production and use volumes of specific foams but the market assessment indicated current supply is in the region of 7,000 to 9,000 tonnes. Anecdotal information from stakeholder consultation notes that “adequate” supply exists and no consultees noted that they had experienced supply constraints in any application. Further discussions with three suppliers indicated current excess production capacity alongside additional capacity for emergencies (not quantified). The consultees noted no constraints with raw material supply.

Production and sales data on one shortlisted product, Epocol, was provided as noted above in Table E.10. This data indicated total production and import capacity of 700 tonnes, with sales of 500 tonnes. Quantitative information was provided on a small number of other specific products. These are not listed above but were stated by consultees as appropriate for use in several applications, including municipal firefighting, storage facilities and marine applications. For these, total volumes produced and imported into the EU totalled a further 550 tonnes, with sales of 380 tonnes. Qualitative information on the availability alternatives was provided via stakeholder consultation on a wider range of products. A total of 22 were stated as being produced in the EU and all of these were commercially available (either in the EU, globally or both). Note that the substance identification and market assessment identified a larger number of products – in the order of 160 – but more detailed information on only a subset of these was obtained via the consultation and the assessment has focused on products for which stakeholders have indicated actual use is taking place.

Using data from the market assessment, Table E.11 provides a quantitative summary of available information. First, the table provides a summary of existing EU demand for PFAS based firefighting foams. This has been split by application, based on Eurofeu survey information. Overall, this indicates current PFAS based foam demand in the region of 18,000 tonnes per year¹⁹⁰, with the largest use in the chemical and petrochemical sector. The

¹⁹⁰ Note that the sum of the sectors is not equal to the total due to rounding.

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second, central, column provides an overview of the volumes of alternative foams that may be expected after a restriction is imposed. This takes into account that additional volumes may be required in some applications.

As in the economic feasibility section above, the analysis has been undertaken assuming no change in the volumes required (central estimate), and a 50% and up to 100% increase, respectively in the volume of foam required in all applications. It is not considered likely that this increase will be required uniformly across all applications; indeed, the stakeholder consultation indicated that many users experienced no overall increase in the volumes required. Finally, the existing demand – again based on Eurofeu survey data – is presented on current fluorine-free foam supply in the EU. The disaggregation of demand by sector is based on the proportions specified in the Eurofeu survey. For both PFAS-based and fluorine-free foams, sector specific volumes are subject to greater uncertainty than the overall totals.

Table E.12 “Top down” assessment – annual demand and supply of PFAS and Fluorine free FFF

Sector of use	Current PFAS foam volumes (t/yr) Central (L-H range (000's))	Existing F- free volumes (t/yr)	Expected future additional demand for F-Free foams Central (L-H range 000's)
Chem cal/Petrochem cal	11,000 (8-12)	2,000 – 2,600	11,000 (8-24)
Municipal Fire Brigades	2,000 (2-3)	3,100-4,000	2,000 (2-6)
Marine Applications	2,000 (2-2)	1,100-1,400	2,000 (2-4)
Airports	2,000 (1-2)	500-600	2,000 (1-4)
Mil tary	2,000 (1-2)	100-200	2,000 (1-4)
Ready for use products	<500	c.100	<500
Total	18,000 (14 – 20)	7,000 – 9,000	18,000 (14 - 40)

Source: Market assessment, desktop research and stakeholder consultation exercise.

The above information indicates that, for all uses, the volumes of fluorine free alternatives would need to increase to meet the replacement demand as users switch from PFAS containing foams under a restriction. Overall, the increase is likely to be in the order of 18,000 tonnes (i.e. sales of 18,000 tonnes of PFAS foam ceases, to be replaced by 18,000 of fluorine free foams), but potentially up to 40,000 tonnes, per year.

Stakeholders indicated that spare foam production capacity exists and that users had not experienced a shortfall in supply. However, RMO 2 may result in a more sudden and potentially significantly larger demand for fluorine free foams, as existing stocks would need to be disposed of and replaced. As noted above, this could be in the region of between 210,000 tonnes and up to a theoretical maximum of 870,000 tonnes of foam. This heightens the risk of a shortfall in supply, - depending on the timescales of any restriction.

Overall, the available evidence clearly indicates a range of alternative foams are currently available on a commercial basis. Moreover, data obtained from stakeholder consultation suggests that in purely quantitative terms existing production capacities can accommodate some increase in demand. For RMO 1, it has not been possible, despite further consultation attempts, to obtain quantitative information on the supply of specific products used in all

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applications, so whilst it is possible, that a shortfall may arise for a specific market segment, the available evidence does not suggest this would be likely. For RMO 2 a much greater quantity of alternatives would be needed to replace existing stocks, with the potential for a shortfall in supply.

As the largest single use, and with comparatively low current fluorine free sales volumes, the risks of supply constraints may be greater in the chemicals and petrochemical sectors (because this is the sector with greatest use) and in RMO 2 (because this would require greater volumes to be replaced in the short term). It follows that appropriate transition periods would further ease this risk.

Whilst there would be costs associated with increasing supply, the market assessment and economic feasibility sections noted above indicated that, on average, the costs for fluorine free foam, on a unit basis, are comparable to or less than those for PFAS based foams. It appears reasonable that manufacturers could continue to increase supply without significant costs having to be passed to downstream users. The range of suppliers and the number of fluorine free products that currently exist on the market would also serve to limit scope for significant price increases.

4.1.9. Other impacts

Other impacts briefly considered in this section include the potential for impacts on international trade and employment and economic competitiveness.

Under RMO 1, PFAS-containing foams in stock will still be able to be used and therefore the demand for replacement with alternatives will be more gradual. It is therefore unlikely that there will be any substantial impacts on competitiveness, trade and employment.

Under RMO 2, there will be a more sudden and larger increase in EU demand for PFAS-free alternative fire-fighting foams and decrease in demand for PFAS-containing fire-fighting foams (again depending on transition period). Imports of PFAS-containing fire-fighting foams into the EU will therefore decrease and manufacturers (both global and EU) of PFAS-containing foams will see a decrease in EU demand. Whilst effects would be mitigated by the fact that at least some manufacturers in the EU are involved in both PFAS and fluorine free foam manufacturing, a potential shortfall in supply – driven by a one off need for stock replacement – may impact imports of fluorine free foam from outside the EU.

Regarding employment, there is no information available on the number of people employed in manufacturing of PFAS-containing fire-fighting foam or manufacturing fluorine-free fire-fighting foam. Overall effects would be neutral or positive, depending on the net effect on volume,

Overall, there are unlikely to be any significant macroeconomic impacts from the result of RMO 1, but with some – albeit temporary risk of increase EU imports under RMO 2.

4.1.10. Emissions from disposal of legacy foams

During the process of disposing of PFAS-containing legacy foams, emissions occur from several sources. In RMO 1, it is expected that a low quantity of legacy foam will be required for disposal. This low quantity will relate to 'transitional wastage' which occurs when a user has some remaining PFAS-containing fire-fighting foam in existing equipment, yet their stock of PFAS-containing firefighting foam has depleted to zero. PFAS-containing and PFAS-free fire-fighting foam cannot be combined in the same system. The low level of PFAS-containing foam left in the container will need to be disposed of. The quantity of foam required for disposal under RMO 1 cannot be accurately quantified as 'transitional wastage' will likely vary across industries and appliances.

In RMO 2, all existing stocks of PFAS-containing foam will need to be disposed of. This section first discusses the disposal options and identifies the potential emissions associated with these disposal options. The quantity of emissions is then estimated and the impact of these

Commented [MD70]: Info to be added on the other RMOs

Commented [MD71]: Further investigation ongoing by Ramboll.

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emissions on health and the environment are discussed. Emissions considered relate to both the potential for remaining PFAS compounds as well as the by-products created from disposal. The analysis focusses on the disposal of unused PFAS-containing foams, rather than the disposal of used PFAS-containing foams. Little data and information was obtained from stakeholder consultation, therefore much of this section is based on desktop research.

- **High-temperature incineration** would appear the most likely disposal option for PFAS-containing legacy foams¹⁹¹;
- **Existing incineration disposal methods used apply a range of temperatures from around 400-6000°C¹⁹²**. The literature also indicates that CF₄ requires temperatures above 1,400°C to decompose and that CF₄ is the most difficult fluorinated organic compound to decompose¹⁹³;
- The effectiveness of PFAS compounds to be destroyed by incineration and “the tendency for formation of fluorinated or mixed halogenated organic by-products is not well understood”¹⁹⁴;
- **The incomplete destruction of PFAS compounds may result in smaller PFAS or products of incomplete combustion being formed¹⁹⁵**. These products may not yet have been researched and therefore have the potential to be chemicals of concern¹⁹⁶;
- **The complete combustion of PFOS/PFAS will result in CO₂, H₂O and HF¹⁹⁷** and the incineration of PFAS at temperatures of at least 1,100°C, usually degrade PFAS to carbon dioxide and hydrogen fluoride¹⁹⁸. It has not yet been determined what is produced when PFAS is incinerated at temperatures lower than 1,100°C¹⁹⁹;
- **Emissions (greenhouse gases and air pollutants) from creating high temperatures for incineration:** There are emissions associated with the procurement and delivery of fuel and with incinerator operation (e.g. greenhouse gases and air pollutants such as particulate matter from the combustion of fuels). Associated emissions have not been analysed and it is assumed that the incinerators would continue to operate at the same temperatures regardless of the type of waste they process. Such emissions were not highlighted by stakeholders in the consultation;
- **Leakage during storage and transportation:** Incineration processes are typically provided off-site and foams will need to be stored and transported to incineration facilities for disposal or waste equipment to be installed on-site²⁰⁰. During the storage and transportation of PFAS-containing foam it may be

¹⁹¹ Derived from stakeholder consultation responses concerning PFAS disposal methods. Note that WWT was also reported as a disposal method, but a judgement was made that these disposal techniques relate to used PFAS-containing firefighting foam rather than unused foam.

¹⁹² Obtained from stakeholder consultation.

¹⁹³ https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfes_incineration_oaa_approved_final_july_2019.pdf

¹⁹⁴ https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfes_incineration_oaa_approved_final_july_2019.pdf

¹⁹⁵ https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfes_incineration_oaa_approved_final_july_2019.pdf

¹⁹⁶ https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfes_incineration_oaa_approved_final_july_2019.pdf

¹⁹⁷ https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfes_incineration_oaa_approved_final_july_2019.pdf

¹⁹⁸ UNEP, 2012 in: <https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-highly-fluorinated-substances-pfas.pdf>

¹⁹⁹ <https://www.kemi.se/global/rapporter/2016/report-11-16-strategy-for-reducing-the-use-of-highly-fluorinated-substances-pfas.pdf>

²⁰⁰ <https://www.serdp-estcp.org/content/download/48955/466822/file/ER18-1593%20Final%20Report.pdf>

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possible for spillages or leakages to occur, resulting in environmental emissions. There has not been enough information identified during desktop based research or provided from stakeholder consultation to accurately quantify these emissions; and

- **Direct emissions (greenhouse gases and air pollutants) from transportation:** Where foams are stored and transported to incineration facilities, direct emissions of carbon and other pollutants (e.g. particulate matter and nitrogen oxides) from vehicles will also occur. Desktop based research revealed a lack of available data regarding the geographical position of PFAS-containing fire-fighting foam manufacturers and users in relation to incineration facilities and little to no information was obtained from stakeholder consultation. It is therefore unsuitable to accurately quantify emissions associated with foam transportation.

Overall, PFAS emissions from incineration are not well studied²⁰¹ and therefore, there is the potential for incineration to be hazardous²⁰². Further research is needed to identify and quantify the emissions produced from the incineration of PFAS, as well as greater research undertaken to understand the thermal properties of PFAS.

An additional stakeholder's consultation and literature search was conducted in 2021 by Ramboll to collect further information, which can be summarised as follows:

Only methods with a complete or maximised defluorination or mineralisation were considered. This excludes the treatment of AFFF concentrates and run-off water in typical municipal and industrial waste water treatment plants and the disposal on landfills as these methods do not effectively destroy the containing PFAS (Houtz et al. 2018).

Furthermore, only large scale established, and financially feasible methods were looked at. If a promising technique was identified which is not yet available at the industrial level it is mentioned in the chapter on emerging techniques.

4.2. Disposal of PFAS-containing firefighting foam concentrates

The incineration of PFAS is according to recent literature and stakeholder input the most reliable method for their destruction. Several authorities and associations also recommend the incineration of PFAS foam concentrate and run-off water as the most efficient method for destruction (AU-EPA 2021; CA-EPA 2021; FFFC 2016).

Also the collected input from stakeholders shows that the only available adequate disposal option for PFAS-containing foams is incineration at high temperatures. Based on available literature, the incineration is performed either in hazardous waste incinerators or cement kilns.

According to literature, some manufacturers and downstream companies offer to take PFAS-based foams back (sometimes only if new fluorine-free foams are purchased). For example, Bio-Ex offered in the past (year 2018-2019) to take back PFAS based AFFF when the same amount of fluorine-free foam was purchased²⁰³.

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²⁰¹ <http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

²⁰² https://www.epa.gov/sites/default/files/2019-09/documents/technical_brief_pfas_incineration_oaa_approved_final_july_2019.pdf

²⁰³ For more information see [here](#) accessed at 01.04.2021

4.2.1. Physical destruction – Incineration in Hazardous Waste Incineration plants

4.2.1.1.1. Background

The strongest bond in a PFAS-molecule is the carbon-fluorine bond with a bond strength of 485 kJ/mol (Roesch et al. 2020). This bond needs to be broken in order to completely destroy a PFAS molecule. The breaking of only the carbon-carbon bonds may lead to the formation of shorter fluorinated molecules, such as ultra-short chain PFAS like trifluoroacetic acid and fluorinated gases like hexafluoro ethane (C₂F₆) and tetrafluoro methane (CF₄). The complete thermal destruction, meaning mineralisation, of a PFAS molecule leads to hydrogen fluoride, water, and CO₂.

4.2.1.1.2. Technical performance

The main principle of waste incineration lies in the thermal breaking of the chemical bonds in a molecule. For this the IED requires European waste incinerators to operate at a minimum temperature of 850°C with a residence time of at least two seconds.

In Europe, for hazardous waste with more than 1 % of halogenated organic substances (what would also apply to PFAS-based firefighting foam run-off and cleaning water) the incinerator needs to reach temperatures of at least 1,100°C (2010/75/EU 2010). The respective incinerators are commonly called hazardous waste incinerators (HWI). To current knowledge, the conditions can break the chemical bonds of a molecule and transform the waste into CO₂, water, salt, and ash.

Hazardous waste incinerators are designed to handle and destroy the most difficult hazardous (explosive and/or toxic) substances. Hazardous waste incinerators have specialized systems for the input of waste material, depending on the type of waste being handled. This is particularly important for some of the most hazardous and toxic wastes. Options include a solid waste bunker, a tank farm for liquid and pasty wastes, drum storage and transportation facilities. For certain (highly reactive) wastes, a dedicated direct injection system is necessary.

The decomposition temperatures for PFAS vary depending on chain length and functional group. PFOA decomposes already at around 100 °C, FOSA at 150 °C, PFHxS and PFOS around 350 °C and PTFE at around 500 °C. At these temperatures the bonds inside the compounds are broken and gaseous fragments are formed. During the decomposition of PTFE fragments such as •CF, •CF₃, •C₂F₄ and •C₃F₅ can be found which indicates, that not all carbon-fluorine bonds were broken (Wang et al. 2015).

To completely mineralise PFAS to hydrogen fluoride, water and CO₂ higher temperatures are needed. According to current literature the temperatures should reach at least 1,100 °C to degrade PFAS to carbon dioxide and hydrogen fluoride (KEMI 2016). The Danish Ministry of Environment published a report on the incineration of persistent organic pollutants (POPs) including PFOS. It is stated, that PFOS will be destroyed to more than 99 % by co-incineration and that other studies have shown a destruction efficiency of more than 99.97 % for fluorotelomers, chlorofluorocarbons and PTFE in conventional waste incineration. It is however also stated, that during the decomposition of PFOS at 900 °C simple fluorocarbons such as CF₄, C₂F₆, CHF₃ and C₂H₂F₂ will be formed (Lundin & Jansson 2017). Among the fluorinated gases tetrafluoro methane (CF₄) is the hardest to destroy, as it only contains carbon-fluorine bonds.

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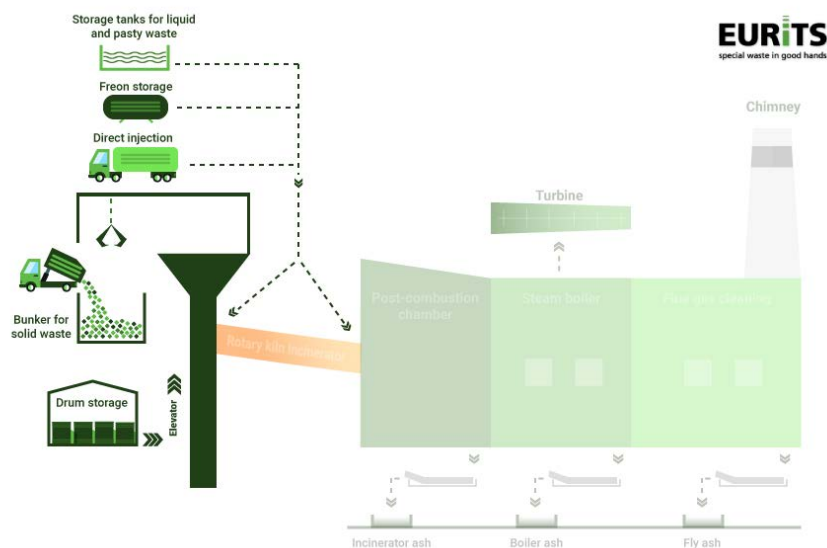


Figure 3: The hazardous waste incinerator process taken from Eurits [homepage](#)

4.2.1.1.3. Side products and emissions

A study performed in 2014 analysed the ash and waters arising from multiple waste incinerators in Sweden. The incinerators generally operated at temperatures above 850 °C and employed a flue gas cleaning process where the flue gas is first pumped through an acidic solution and then through a neutral step where sulphur dioxides are separated through the addition of lye. While multiple PFAS could be found in all sampled media the authors conclude that as the amounts were so low that waste incineration plants in Sweden are unlikely to contribute significantly

to environmental emissions of PFAA (Sandblom 2014).

According to data from the US, the end product of the complete combustion of any organic compound will lead to carbon dioxide and water which will be emitted to the air. In the case of PFAS, hydrogen fluoride will also be formed if the compound is completely destroyed. It can be found in the bottom ash as well as the flue gas. In order to remove the HF from the gas a gas scrubber is applied. For this the hot flue gas is cooled in a quenching unit filled with water whereby the HF dissolves in the water. This step is then repeated with a multistep scrubbing tower where the flue gas is scrubbed with a sodium hydroxide solution to remove all remaining HF. The resulting effluent is then quenched in a calcium hydroxide solution where the dissolved fluorine precipitates as calcium fluoride. As this method employs an alkaline solution it may also remove any airborne charged PFAS such as PFCA and PFSA but can however not remove fluorinated gases(US-EPA 2020a).

If the temperature is too low products of incomplete destruction will be formed. These include for example CF₄, C₂F₆, CHF₃, C₂H₂F₂ and C₃F₈(DK-EPA 2019; US-EPA 2020a).

A quantitative analysis of the formation of these fluorinated gases during the combustion of PFAS has not yet been performed. In general, these gases have a high greenhouse gas potential and should be avoided. As the PFAS destruction efficiency of the thermal treatment is not 100 %, small amounts of PFAS will not be destroyed and as such can be emitted to air or be found in the fly and bottom ash. The ashes are often landfilled and the contained PFAS

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can thus be washed out and emitted into the water and ground. However, based on data from Sweden, PFAS concentrations in fly and bottom ash are very low (26 – 748.3 pg/g) (Wohlin 2020).

Another study concluded that in total less than 10 kg of PFAA are deposited on Swedish landfills per year from ash from waste incinerators (Sandblom 2014).

Data from stakeholder interviews indicate that there is a need for standardisation and future scientific investigations:

- One stakeholder from Germany made it clear that there is still a need for research with regard to the incineration of PFAS-containing wastes and the associated issues, particularly with regard to the required minimum temperatures and possible products of incomplete incineration. In the past, investigations have already been carried out, for example at household waste incineration plants, but these often focused on individual substances such as PFOA and PFOS or long-chain compounds. Although it can be assumed that these compounds break down at sufficiently high temperatures and long residence times, the extent to which short-chain compounds or products of incomplete combustion (PICs) are formed or emitted and how these are to be evaluated has not yet been sufficiently researched according to current knowledge (LASTFIRE-Interview 2021).
- Another stakeholder from Germany stated that currently measured background levels of PFAS substances must come via incineration. According to measurements in Bavaria, when PFAS is measured in soil 50% of taken samples would be over current threshold levels as defined by the Bavarian PFC assessment guidelines (measurements based on DIN 38414-14) (LfU-Gierig-Interview 2021).
- The same stakeholder also indicated that so far, there are no validated measurement methods for the determination of PFAS in exhaust air. However, a DIN-standard for the determination of PFAS in exhaust air is drafted right now. The stakeholder guessed it will take approx. 2-3 years to publish it (LfU-Gierig-Interview 2021).

4.2.1.1.4. Availability across the EU

According to the Nordics Council of Ministers there are 808 incineration facilities in Europe, including hazardous and municipal waste incinerators (NordicCouncil 2019).

The Confederation of European Waste-of-Energy Plants reported in 2018 that there are 492 waste to energy plants operating in Europe. This number does not include the hazardous waste incineration plants. In total the 492 plants treated 96 million tonnes of waste in 2018 (CEWEP 2018)²⁰⁴. Hazardous Waste Europe represents 155 hazardous waste treatment installations in Europe with a total treatment capacity of 4.6 million tonnes per year. These facilities however also include non-incineration processes such as biological treatment and landfills²⁰⁵.

Another association, the European Union for Responsible Treatment of Special Waste – EURITS, shows on its homepage the availability of HWI across the EU (see Figure 2). Of course, this overview only includes member companies of this respective association.

Based on the overview it can be assumed, that HWI availability differs across Europe. This is in line with a stakeholder comment from Norway who reported that there is no HWI available

²⁰⁴ Assuming that the difference between the 808 incineration facilities and the 492 waste to energy plants are hazardous waste incinerators it could be assumed, that there are 316 hazardous waste incinerators in Europe. However, the exact numbers are not known.

²⁰⁵ Numbers are taken from the respective homepage, see [here](#) accessed at 01.04.2021

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in Norway, thus PFAS-based AFFF was sent to cement kilns (see also next chapter) (Equinor-Ystanes-Interview 2021). Another stakeholder from the Netherlands indicated that there would be no such incineration plant in the Netherlands. Neighbouring countries Belgium and Germany would have these (LEC-BrandweerBRZO-Submission 2021).



Figure 4: Availability of HWI across the EU taken from Eurits [homepage](#)

According to the German Federal Environmental Agency there are 29 hazardous waste incinerators in Germany with a total capacity of 1,520,490 million tonnes per year²⁰⁶.

The WI BREF reported 121 hazardous waste incinerators in Europe in 2019 with a total capacity of 6.75 million tonnes of waste per year however the exact incineration conditions are unknown.

Costs²⁰⁷

According to the Wood's report the cost to incinerate one PFAS-containing AFFF litre range between 0.3 – 1.5 €/l (Wood et al. 2020). This range is in accordance to the data gathered in the stakeholder engagement and literature review of this project:

- On their website, the Rosenbauer Group reports a price of 200 – 400 €/m³ for the high temperature disposal of PFAS-containing AFFF, which corresponds to 0.2 – 0.4 €/l²⁰⁸.

²⁰⁶ Numbers are taken from the respective homepage, see [here](#) accessed at 01.04.2021

²⁰⁷ The following assumptions have been considered: density of PFAS-containing AFFF is approximated to be 1 kg/m³ and exchange rate Euro to US dollar of around 1,2:1 (as of 01st of April 2021)

²⁰⁸ Numbers are taken from the respective homepage, see [here](#) accessed at 01.04.2021

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- Also, another company from Germany offers to take back foams for 1 – 2 €/l²⁰⁹.
- A stakeholder from Germany named a price of 700 €/t for the incineration of PFAS-containing AFFF which corresponds to 0.7 €/l (DUS-Valentin-Interview 2021).
- Another stakeholder from Germany named a price of about 400 - 600 €/t, which corresponds to 0.4-0.6 €/l (LfU-Gierig-Interview 2021).
- Another stakeholder from Germany named prices between 700-1000 €/t, which corresponds to 0.7-1 €/l. The specification of the fluorine content before incineration is obligatory [REDACTED] Interview 2021).

Higher prices are reported for the US and Australia. The US EPA published an interim guide on the destruction of PFAS where a price for liquid halogenated hazardous waste of 1,218 – 1,770 \$/ton is stated. This corresponds to roughly 1 – 1.46 €/l (US-EPA 2020b). For Australia € 2,000 per m³ are reported, which corresponds to 2 €/l²¹⁰.

4.2.1.1.5. Additional information and available case studies

- According to one stakeholder from Germany, incineration plans often do not accept PFAS-based AFFF, because of its foaming capacities (the liquid waste is fed into the combustion chamber through a nozzle) and the formation of HF-acid (corrodes the tiling). This could lead to the fact that the prices for AFFF-incinerations will increase in the future ([REDACTED] Interview 2021).
- On stakeholder from Germany stated that the only publicly accessible plant for a thermal treatment of waste containing PFCs in Bavaria is GSB - Sonderabfall-Entsorgung Bayern GmbH in Ebenhausen near Ingolstadt. The incineration plant consists of 2 lines with a total annual throughput of approximately 220,000 tons. In 2020, GSB thermally disposed of about 834 t of waste from the segment of extinguishing foam, extinguishing water, extinguishing agents, for which at least a PFC contamination could not be excluded in principle; only 23.88 t of foam extinguishing agents, extinguishing foam, extinguishing water contain a specific reference to PFC or PFT in the waste designation. Since the exhaust gas cleaning technology used in Ebenhausen consists, among other things, of various scrubber stages, which generally ensured a high separation of halogenated pollutant compounds such as HF, the emission of HF is far below the legal limit. Combustion temperatures average 1080°C in the rotary kiln and 1000°C in the afterburner chamber. Thermal destruction of components containing PFC/PFT can therefore be assumed with a high degree of probability (LfU-Gierig-Interview 2021).
- A stakeholder from the Netherlands brought up the idea to set up consortia in different regions in Europe for the destruction of foam concentrates. Many parties (public and private) will soon have foam concentrates that may no longer be used. Tackling this together seems a good option for cost-efficient and environmentally friendly solutions (LEC-BrandweerBRZO-Submission 2021).

4.2.2. Physical destruction – Incineration in cement kilns

4.2.2.1.1. Background

According to (Lundin & Jansson 2017), cement kilns typically consist of a long cylinder of 50–150 meters in length, inclined slightly from the horizontal (3% to 4% gradient), which is rotated at about 1-4 revolutions per minute. Raw materials such as limestone, silica, alumina,

²⁰⁹ Numbers are taken from the respective homepage, see [here](#) accessed at 01.04.2021

²¹⁰ See comment on Rosenbauer homepage, see [here](#) accessed at 01.04.2021

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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, where material temperatures reach 1,400°C–1,500°C. The fuel used to heat the rotary kiln has traditionally been coal, but lately different kinds of waste fractions have been utilized in some plants.

Wang et al. published a paper in 2015 indicating, that the addition of calcium hydroxide can catalyse the defluorination process of PFAS. At temperatures of 900 °C this method showed high transformation rates, indicated by the formation of calcium fluoride. For PFOS a transformation rate of 90 % was achieved with even better results for PFHxS. PFOA and FOSA however only reached transformation ratios of around 50 % suggesting, that the functional group has an influence on the efficacy of the method. PTFE reached transformation ratios of 80 % already at a temperature of 400 °C (Wang et al. 2015). Comparing this to the decomposition temperature of 500 °C for PTFE, the calcium salts can lower the needed reaction temperature by 100 °C. This research suggests that the addition of these salts to the incineration process can lower the formation of fluorinated gases.

According to data from Australia, the advantage of adding PFAS waste to the production of clinker in cement kilns, is that no extra energy is required to destroy the PFAS and additionally the quality of the clinker can be enhanced through the addition of fluorine (Holmes & Queensland 2020b). Fluorinated substances react in the cement production process as mineralizers, which can promote the formation of a specific phase altering the thermodynamic equilibrium of reactions. Mineralizers are more efficient in the presence of a liquid phase and can contribute to the flux activity. Next to fluorine other examples are: Zinc, Manganese, Sulphur, among others (Cemex 2013). The addition of fluoride has proven to increase the reactivity of clinker used in cement as well as reducing the amount of clinker needed. Typical fluorine addition rates are 0.2 % by weight of clinker to achieve mineralisation without adverse effects (Cooper 2014).

Fluorine is often added in the form of calcium fluoride to the cement kiln but can also be added in the form of PFAS, however the calcium fluoride content should not be lower than 40%. The inclusion of calcium fluoride can decrease the burning temperature by 100 °C (Cemex 2013). As limestone (calcium and magnesium carbonate) is an ingredient for the production of clinker PFAS could be added to form in situ calcium fluoride (CaF₂) in the cement kiln.

The preferred method of introduction of PFAS wastes is by blending the foam concentrate or any other liquid wastes into the alternative fuels (waste oils) so as to control and minimise the water content that would otherwise disturb the temperature of the burner flame. Solid wastes such as PFAS contaminated GAC and resins can also be introduced packaged in 20L buckets at a suitable point in the kiln as is currently done for clinical and drug wastes. Overall, it is considered that the use of cement kilns for PFAS destruction represents the best option based on the very large safety margins in the normal production conditions for complete destruction (calcium, high temperature, long residence times), permanent capture of the fluorine as inert, insoluble, non-toxic minerals, no need to modify kiln equipment, and no need for additional fuel/energy costs (Holmes & Queensland 2020a).

4.2.2.1.2. Technical performance

The cement kiln generally operates at temperatures between 800 – 1,800 °C depending on which process step with a total residence time of about 25 minutes. At the hottest point the residence time at ~17 – 21 seconds at 1,800 °C (Holmes & Queensland 2020b), which according to recent literature is hot enough to even destroy CF₄. As such this technology can be used to effectively destroy PFAS and at the same time produce cement clinker.

The Queensland government in Australia has already conducted a trial run with a total fluorine input of 325kg/h from which 5kg/h was from PFAS. As a result, no PFAS and only minimal amounts of hydrogen fluoride could be detected after the burning process. The quality of the clinker was unaffected (Holmes & Queensland 2020b).

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Also, according to US-EPA, the temperature at which the cement kilns operate (usually around 1400°C-2000 °C) allows for full destruction of PFAS compounds and the residence time (6-10 sec) is believed to be sufficient (Patterson & Dastgheib 2020).

For conventional waste incinerators on average ~354 – 534 kWh/m³ of energy is needed at 1,100 °C for the burning of waste (Holmes & Queensland 2020b). Maga et al. state an energy demand for the high temperature incineration of AFFF containing spent fire-extinguishing water at 1,100 °C of 1,312 kWh/m³ (Maga et al. 2021a). This value is higher due to the added energy needed to vaporise the water.

4.2.2.1.3. Side products and emissions

According to stakeholder knowledge, cement kilns do not possess the same filter techniques as incinerators handling hazardous waste (HWI). This needs to be considered when emissions are discussed (DUS-Valentin-Interview 2021). However, there are no standardized methods to monitor PFAS in exhaust air from incinerators as discussed above.

Other Stakeholders also indicated, that there is no knowledge about a possible PFAS-contamination (or other fluorinated side products) of the end product (cement) (LASTFIRE-Interview 2021).

Data from Australia however, indicate that when PFAS introduced to both the main burner and the calciner produced results of very high destruction efficiencies with no PFAS in flue gases and no change to the usual emissions of very low levels of HF in normal clinker production. A significant point to note is that the trial runs of destruction of PFAS at 5kg/hr (as F) were done with and without the input of aluminium smelter cell waste materials with fluorine throughput of 325kg/hr (as F). The destruction of the fluorine-containing (~15%) spent cell carbon and refractory waste has been common practice in cement kilns for decades with low HF emissions demonstrating the very high efficiency of fluorine capture by calcium and the failure of the carbon and fluorine to recombine into PFAS. The Cement Australia kiln at Gladstone is licensed to destroy up to 5kg/hr PFAS (as F) based on the maximum throughput rate in the trials (at ~€4.50/L). However, the other larger fluorine inputs with no significant HF or PFAS outputs suggest that greater throughputs of PFAS wastes could be destroyed just as effectively as the 5kg/hr (as F) in the licence (Holmes & Queensland 2020a)..

4.2.2.1.4. Availability across the EU

According to the best available techniques reference document for the production of cement, lime and magnesium oxide, there are 268 cement kilns in Europe. In 2004 6.1 million tonnes of waste was used as fuel in cement kilns from which one million tonnes were hazardous waste. It is also stated that in 2007 17% of fuels was sourced from waste (CLM-BREF 2013).

German authorities are not aware that the incineration of PFAS-based foams in cement kilns are taking place in Germany (DUS-Valentin-Interview 2021; LASTFIRE-Interview 2021; LfU-Gierig-Interview 2021). According to other stakeholders this is a developing field in the EU (LASTFIRE-Interview 2021). Based on desktop search, also no other cases are reported. However, in Australia calcium catalysed destruction in cement kilns is currently best practice (Holmes 2020) .

4.2.2.1.5. Costs

- One stakeholder indicated costs for incineration in cement kiln in Norway of 1-2\$/litre, what would correspond to 0.85 to 1.7 €/l (Equinor-Ystanes-Interview 2021).
- Australian Stakeholder indicate a cost of €4.50/L (Holmes & Queensland 2020a).

This price (EU-based) is comparable to the prices reported for HWIs (0.2 – 2 €/l).

4.2.2.1.6. Additional information and available case studies

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- One stakeholder sent its waste to a cement kiln ([Norcem](#) in Brevik) in Norway, which uses temperatures of 2,000 °C. To his knowledge this would be the only waste disposal option in Norway, as most municipal waste incinerators operate at lower temperatures (800 °C) (Equinor-Ystanes-Interview 2021).

4.3. Conclusion on the disposal of PFAS-containing firefighting foam concentrates

The incineration of PFAS-containing AFFF is the most used disposal method. Literature indicates that waste incinerators at temperatures of 900 °C are able to destroy PFOS at more than 99%. A destruction efficiency of more than 99.97 % for fluorotelomers, chlorofluorocarbons and PTFE in conventional waste incineration was also reported. However, this process might not lead to the complete mineralisation of the PFAS i.e. the decomposition of the PFAS to CO₂, water, and hydrogen fluoride. At these temperatures short chain fluorinated compounds such as CF₄, C₂F₆, CHF₃, C₂H₂F₂ and C₃F₈ can be formed and released to the air. Literature indicates that temperatures of at least 1,400 °C are needed to destroy CF₄ and as such completely mineralise the PFAS. Literature indicates, that 1,100 °C is sufficiently hot and feasible for the destruction of PFAS, however no study has provided quantitative results on possible fluorinated gas emissions.

The average cost of approximately 1€/l (range is 0.2-2 €/l) is comparatively cheap but the process requires high amounts of energy as the water needs to be vapourised. No actual data has been found that would indicate that the cost for incineration increased recently or will increase in the future. However, based on input of a stakeholder, the capacity is an issue for some hazardous waste incinerators, as not all of them can handle large amounts of liquid waste and foaming can cause issues, when it is stored intermediately with other liquid waste (WFVD & [REDACTED] 2021). Also, according to another stakeholder from Germany, incineration plans often do not accept PFAS-based AFFF, because of its foaming capacities (the liquid waste is fed into the combustion chamber through a nozzle) and the formation of HF-acid (corrodes the tiling). This could lead to the fact that the prices for AFFF-incinerations will increase in the future ([REDACTED] Interview 2021).

The co-incineration of PFAS waste in cement kilns is a viable alternative to incineration in HWI, as these kilns reach temperatures of up to 1,800 °C with residence times of ~20 seconds. It has been shown that the addition of calcium fluoride can increase the quality of the clinker. Additionally, calcium salts can decrease the decomposition temperature of PFAS and increase the mineralisation rate by forming calcium fluoride. Through the addition of PFAS-containing waste to the clinker production in-situ calcium fluoride can be formed, which can increase the clinker quality and destroy the PFAS. The applicability of liquid AFFF concentrate in the cement kilns in the EU is rather unclear. German authorities are not aware that the incineration of PFAS-based foams in cement kilns are taking place in Germany (DUS-Valentin-Interview 2021; LfU-Gierig-Interview 2021). One stakeholder from Norway indicated that his company sent PFAS-based firefighting foams to a cement kiln as there is no HWI available in Norway (Equinor-Ystanes-Interview 2021). No costs have been reported for this case. In Australia calcium catalysed destruction in cement kilns is well established and currently best practice (Holmes 2020). Australian Stakeholder indicate a cost of €4.50/L (Holmes & Queensland 2020a).

However, stakeholders from Germany indicated, that cement kilns don't have the same filter techniques as HWIs (DUS-Valentin-Interview 2021). In addition, stakeholders from Germany are concerned that the cement could also be contaminated (DUS-Valentin-Interview 2021). However, data from Australia indicate no contamination of the cement and a very high destruction efficiencies with no PFAS in flue gases and no change to the usual emissions of very low levels of HF in normal clinker production (Holmes & Queensland 2020a).

According to German federal environmental authorities the degree of destruction of PFASs (e.g. related to the input concentration) during incineration is not well understood. In general, there is still a need for research concerning the incineration of PFAS-containing wastes and thus also of AFFF concentrates (LANUV-Voland-Response 2021).

Table X: Comparison between incineration techniques for PFAS-based AFFF in HWI (hazardous waste incinerators and cement kilns)

	Incineration in HWI	Incineration in cement kilns
Background	Literature indicates that hazardous waste incinerators at temperatures of 1,100 °C are able to destroy PFAS at more than 99%.	The co-incineration of PFAS waste in cement kilns is a viable option to incineration in HWI, as these kilns reach temperatures of up to 1,800 °C with residence times of ~20 seconds.
Technical performance	According to current knowledge high temperature incineration in HWIs is an adequate technique to dispose, as PFAS are to more than 99% mineralised.	Data from Australia and the US indicates, that PFAS can completely mineralized in cement kilns.
Side products & Emissions	There are uncertainties concerning the emission of fluorinated substances, that could be produced when PFAS-based foams are incinerated. However, there is also no official standard to measure fluorinated substances in exhaust air. Currently, a standard for the measurement of fluorinated substances in exhaust air is being drafted.	One stakeholder from German indicates, that cement kilns are not having the same filter techniques as HWIs (DUS-Valentin-Interview 2021). In addition, also the cement could be contaminated (LANUV-Voland-Response 2021). However, data from Australia indicate no contamination of the cement and a very high destruction efficiencies with no PFAS in flue gases and no change to the usual emissions of very low levels of HF in normal clinker production (Holmes & Queensland 2020a)
Availability	The availability of HWI in Europe is different for each member state. Some countries do not have HWI and therefore need to transport their PFAS-based AFFF waste across borders.	According to the best available techniques reference document to produce cement, lime and magnesium oxide, there are 268 cement kilns in Europe.
Costs	0.2-2 €/l.	0.85 - 1.7 €/l

4.3.1. (Technical feasibility / availability of disposal options (legacy foams))

This section assesses the potential for existing disposal options to feasibly dispose of legacy foams in RMO 2. The disposal of legacy foams is not considered in RMO 1, as existing stocks will still be able to be used until they run out. With RMO 2, a sudden increase in the short-term demand for disposal will likely occur as the whole market will dispose of their stocks to enable replacement. The level of demand for disposal will depend on what transition period is established (yet to be determined). In order to meet the demand, existing disposal options must have the capacity to process the quantities of foam to be sent for disposal. This subsection identifies the disposal options available and discusses their capacity to process and dispose of PFAS-containing foams given a sudden increase.

There are several incineration methods available. One stakeholder reported two specific and different incineration methods: cement kiln and plasma arc furnace. A cement kiln operating from around 400°C has a retention time of 20 minutes. A cement kiln operating between around 850-1800°C has a residence 16-24 seconds (with a minimum of 2 seconds). Estimated costs of PFAS disposal by cement kiln incineration are around €2/l. Another stakeholder who

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has transitioned to fluorine-free foams also reported that their stocks of PFAS-based foams were incinerated in a cement kiln, but reported costs around €1 per litre. Plasma arc furnace conditions can reach 6000°C and have an estimated processing cost of €11/l.²¹¹ It would therefore appear that costs are higher for incinerators operating at higher temperatures and there is a **potential trade-off between the cost of incineration, effectiveness of PFAS destruction and time**, due to higher temperatures being more likely to completely destroy the PFAS.

With the sudden increase in short-term demand for incineration, existing disposal methods would need to be sufficient to process the volume of legacy PFAS foams required to be disposed of. Where capacity is insufficient, the storage of the foam will likely be required. The following assumptions are made to derive the capacity for existing incinerators to process PFAS-containing foam and the time it would take to complete this (not taking into account transportation times):

- The literature indicates that there are **808 incineration facilities across EU28**²¹². These include high temperature hazardous waste incinerators as well as municipal waste incinerators that probably operate at lower temperatures. However, according to the Industrial Emissions Directive²¹³ Article 50, all incinerators need to be designed, equipped, built and operated so that a temperature of at least 850°C is achieved for at least two seconds. It is therefore assumed that all 808 incinerators are able to operate at least at 850°C. However, as discussed in the previous sub-section, at least 1,100°C (or for some PFAS even at least 1,400°C) are required to degrade PFAS to carbon dioxide and hydrogen fluoride and it has not yet been determined what is produced when PFAS is incinerated at lower temperatures. Data was not available to determine the share of EU incineration facilities that achieves 1,100-1,400°C;
- The **amount of PFAS-containing legacy foam for disposal is between 210,000 tonnes and 435,000 tonnes (average 322,500 tonnes)**;
- Information obtained from stakeholder consultation indicates that an incinerator operating at around 850-1800°C can process one tonne of foam per hour and an incinerator operating at around 6000°C has a throughput of around 25l per hour. It is assumed that 1kg = 1l; and
- It is also assumed that incinerators continuously operate with the same processing capacity and at the same temperature, 24 hours a day.

Based on the above assumptions, the tables below provide estimates of the time it will take incinerators to dispose of fire-fighting foams based on 808 incinerators having a processing capacity of 25l per hour or one tonne per hour. As discussed above, to ensure adequate destruction of PFAS, it would appear to be preferable to dispose of PFAS-containing firefighting foams at incinerators with higher temperatures (at least 1,100-1,400°C). This will therefore reduce the capacity available and increase the time period required for disposal.

²¹¹ Obtained from stakeholder consultat on. Note that t is not clear whether this relates to foam concentrate or other foam types being processed.

²¹² The Cost of Inaction - <http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

²¹³ Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

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Table E.13 Processing time based on existing incinerator capacity processing 25l per hour.

Foam to be disposed of (tonnes)	Time for foam to be disposed of (hours)	Time for foam to be disposed of (days)
210,000 (low)	10,400	400
322,500 (average)	16,000	700
435,000 (high)	21,500	900

Note that all cost values are assumed to represent the cost of disposal of unused PFAS-containing fire-fighting foams and not used PFAS-containing firefighting foam. Source: market assessment, desktop research and stakeholder consultation. Values have been rounded.

Table E.14 Processing time based on existing incinerator capacity processing one tonne per hour.

Foam to be disposed of (tonnes)	Time for foam to be disposed of (hours)	Time for foam to be disposed of (days)
210,000 (low)	260	10
322,500 (average)	400	20
435,000 (high)	540	20

Note that all cost values are assumed to represent the cost of disposal of unused PFAS-containing fire-fighting foams and not used PFAS-containing firefighting foam. Source: market assessment, desktop research and stakeholder consultation. Values have been rounded.

Responses from the stakeholder consultation indicate that there is sufficient capacity for disposal of PFAS-containing foams. One stakeholder reports that there is sufficient capacity for disposal, but that getting high-temperature incineration capacities is becoming more difficult. Another stakeholder also reports that sufficient capacity for disposal by incineration is not guaranteed. Capacity for disposal is also likely to depend on the transition period chosen (yet to be determined) and was mentioned in the stakeholder consultation. If the transition period is short, there is the potential for demand for disposal facilities to outstrip supply. A longer transition period is more likely to result in the demand and the quantities sent for disposal being spread over a greater time period. Alternatively, a sector by sector introduction of RMO 2 could be introduced to also spread the demand for disposal over time and avoid destruction capacity being exceeded²¹⁴. Note that it is not clear whether stakeholder responses relate to used foams or whether responses relate to the sufficient capacity for the disposal of legacy foams if RMO 2 were to occur. Additionally, the geographical locations of incinerators, the feasibility of storing and transporting PFAS to destruction facilities as well as the availability of transportation vehicles and labour has not been evaluated due to lack of information from both desktop-based research and stakeholder consultation. Further, the knock-on effects on other sectors requiring use of incineration facilities have not been considered.

4.3.2. Costs of disposal of legacy foams

This section discusses the costs associated with the disposal of legacy PFAS-containing firefighting foams under RMO 2. Costs occur from the disposal process itself, as well as from transportation to disposal facilities and the storage of PFAS-foams. Costs of disposal are not considered to be incurred in RMO 1, unless 'transitional wastage' occurs, where the disposal of some PFAS-containing foam must happen to enable a switch to an alternative. Information

²¹⁴ Obtained from stakeholder consultation.

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and data is unavailable to accurately quantify the amount of 'transitional wastage'. This subsection therefore focuses on costs associated with RMO 2. First, the direct cost of incineration is calculated based on the stocks required for disposal. Costs associated with transportation to incinerators, labour costs and the potential costs of storage are qualitatively discussed.

Incineration costs

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Incineration costs refer to the direct cost charged for the incineration of PFAS waste. Obtained from stakeholder consultation, the costs of disposal by incineration at temperatures between 850-1800°C are between around €0.3-1.5 per litre²¹⁵. Two stakeholders who have transitioned to fluorine-free foams both reported that their stocks of PFAS-based foams have been incinerated at costs of around €1 per litre. For incineration at a higher temperature of around 6000°C, a cost of around €11/l is estimated. It is therefore considered more costly to dispose of PFAS-contained foams at incinerators with higher temperatures. Table E.14 provides estimates of the cost for the disposal based on the total amount of PFAS-containing fire-fighting foam to be disposed of at 322,500 tonnes (average), 210,000 tonnes (low) and 435,000 tonnes (high).

Table E.15 Estimated costs of disposal

Foam to be disposed of (tonnes) Best estimate	Cost of disposal (€/l): L-M-H	€0.3 (low)	€1.0 (best estimate)	€11 (high)
210,000 (low)		63m	210m	2,310m
322,500 (average)		97m	323m	3,547m
435,000 (high)		130m	435m	4,785m

Note that all cost values are assumed to represent the cost of disposal of unused PFAS-containing fire-fighting foams and not used PFAS-containing firefighting foam. Source: market assessment, desktop research and stakeholder consultation. Values have been rounded.

However, it should be noted that at least part of the PFAS-containing fire-fighting foams would reach their expiry date without being used and therefore be incinerated in any case, just at a later date. For these foams, a restriction on the use of PFAS-based fire-fighting foams would only bring their incineration forward and therefore the incineration cost of fire-fighting foams that would have expired is not additional to the baseline, i.e. not a cost of the restriction. As discussed earlier²¹⁶, it is not known what share of fire-fighting foams is used before its expiry date, but if reported usage rates of 15-20% per annum of existing stocks is an average across all sectors of use, there will be some installations with potentially far lower usage rates annually that will likely have some foams that reach expiry before use. Hence, an unknown share of the costs are not additional to the baseline and the costs presented in Table E.14 should be considered a higher boundary of the actual cost of the restriction in terms of the costs of disposal of legacy foams.

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²¹⁵ Note that it is not clear overall whether stakeholder consultation responses refer to foam concentrate or another measure of foam. One stakeholder explicitly reports disposal costs at €1 to €1.5/m³ of foam concentrate for high temperature incineration (1,100-1,200°C). €1/l is considered a middle value due to stakeholder consultation reporting this is the cost of disposing of old foam. Not all costs were provided in euros and conversion rates have been used. It has also been assumed that 1kg = 1l.

²¹⁶ In the emissions assessment in Section B.9) and the section on savings from adoption of fluorine-free foams ("e. Impacts associated with the economic feasibility of alternatives").

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Transportation costs

Stakeholder responses did not identify transportation costs in relation to the costs of disposal. However, it is possible that transportation costs may occur where PFAS-containing fire-fighting foams need to be transported to incinerators off-site. These may include the costs associated with vehicle operation such as fuel costs (which will likely vary across the EU and be dependent on fuel prices) and distance covered between the pick-up point for PFAS and the site for incineration. Desktop based research reveals that Greece has the highest number of incinerators (132), followed by Belgium (100), Italy (100), Germany (93), the UK (87) and Poland (85)²¹⁷. However, without detailed information concerning the location of PFAS foam users and manufacturers, it is not feasible to derive accurate transportation costs associated with disposal.

Storage costs

Stakeholder responses referred to storage costs within the context of requiring multiple foams to be stocked, particularly during a transition to PFAS-free foam, rather than within the context of disposal. This cost could be mitigated through phased transition. These costs have not been quantified here.

Labour costs

Labour costs may be incurred during the collection of PFAS-containing firefighting foams as well as during their transportation to incineration facilities. Stakeholder consultation did not provide any responses relating to labour costs for the disposal of PFAS and these would likely form part of the overall incineration costs.

4.3.3. Disposal of PFAS-contaminated (fire run off and cleaning) water

A stakeholders survey and literature search performed in 2021 by Ramboll provided the below information on the available techniques and costs for disposal of run-off waters contaminated with PFAS.

4.4. Description of the problem

4.4.1.1.1. General Treatment of PFAS-contaminated water

As shown above, the current go-to technique for the disposal of PFAS-containing firefighting foam is incineration either in incineration plants and/or cement kilns. Incineration at high temperatures is a destructive technique and leads to the mineralisation of PFAS.

For PFAS-containing fire run off water (and any other PFAS contaminated water), the treatment methods and successive disposal methods can be distinguished between non-destructive and destructive techniques, whereby the final destruction of PFAS is in most cases also a succeeding incineration at high temperatures. Generally, it is not well known, what happens to run off water after a fire incident. Based on stakeholder input, it is known, that companies (at least in Germany) which are regulated by the L6R6RL contain run off water. Other fire run off water from fires that happen outside these facilities (municipal fires) is not well contained. This is also true for marine applications. This will be again highlighted in the a sperate section of this report (see What happens to fire-run off water?)

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²¹⁷ <http://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

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According to JOIFF, from a waste management perspective, treating foam concentrates and spent foam mixtures resulting from AFFF and fluoroprotein foams used in fire incidents is not possible using biological treatment processes. Conventional wastewater treatment plants will not breakdown non-biodegradable PFASs. Discharge of these wastes to sewer is therefore not an effective treatment (JOIFF 2020).

In 2020, UBA together with Arcadis highlighted in a review article all available PFAS treatment technologies for groundwater and ranged them according to their practicality (UBA 2020). In Figure 3 a visual summary of this overview is shown.

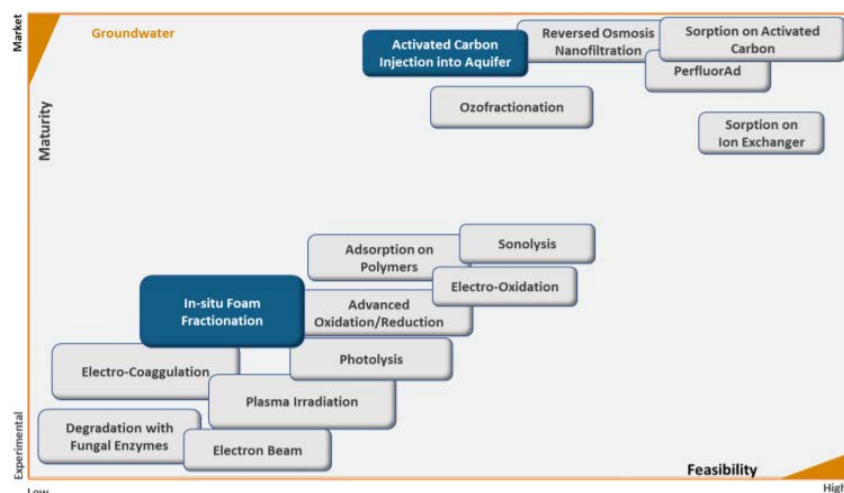


Figure 5: PFAS treatment technologies for water, ranged according to their practicality (taken from (UBA 2020)).

When PFAS treatment technologies for water are discussed the volume of the water and the proportional PFAS-concentration need to be considered.

According to Horst et al., the current state of the practice for treating water contaminated with PFAS is to take extremely large volumes with low PFAS concentrations – typically in the part per trillion range (ppt; i.e., nanogram per litre [ng/L]); and convert it into much smaller volumes of high PFAS concentration, which can then be more economically treated using technologies attempting to destroy PFAS (Horst et al. 2020). In Figure 4 the conceptual impact of volume on the relevance of currently available non-destructive and destructive treatment approaches for PFAS contaminated water is shown.

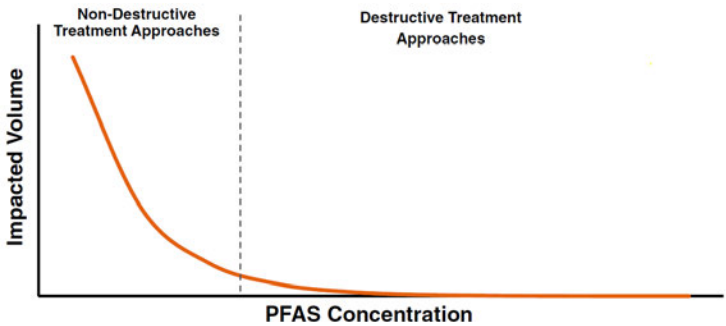


Figure 6: Conceptual impact of volume on the relevance of currently available non-destructive and destructive treatment approaches for PFAS contaminated water (taken from (Horst et al. 2020))

Fire run off water and cleaning water

In the context of this project, only feasible and mature techniques for the treatment of fire run off and cleaning water (shown in Figure 5 in the green box) have been analysed in detail. For both PFAS-contaminated water types it is assumed that a rather high PFAS-concentration is to be expected. For example, PerfluorAd is designed for treating water containing PFAS concentrations greater than 0.3 µg/L (Ross et al. 2018).

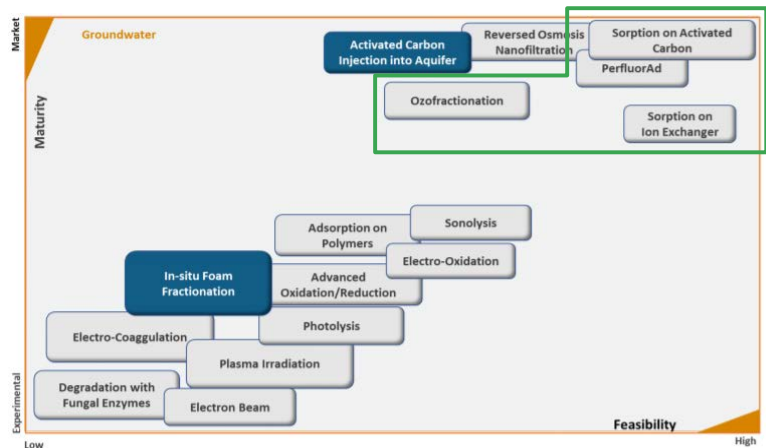


Figure 7: PFAS treatment technologies for water, ranged according to their practicality (taken from (UBA 2020)).

Available techniques focussing on in situ techniques for groundwater are not considered (e.g. activated carbon injection into aquifer²¹⁸), as they lack market maturity and are not compatible with both types of water (Concawe 2020).

²¹⁸²¹⁸ According to the national geographic society an aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt). Groundwater can be

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In addition, those technique for which no references were available for treatment of fire-extinguishing waters or water with PFAS concentrations within the range of fire-extinguishing waters have been also not analysed.

According to Concawe, for the following techniques there are no reported case studies regarding fire-extinguishing water treatment:

- Electrochemical degradation
- Sono-chemistry
- UV-radiation
- Plasma treatment

These non-destructive and destructive treatment techniques have therefore not been considered. The techniques have been analysed and updated based on current available literature (predominantly the ITRC-guideline (ITRC 2020) and a review of water treatment systems for PFAS removal from Concawe (Concawe 2020)) and finally stakeholder input.

According to UBA, the treatment of high AFFF-contaminated water poses a challenge. With the help of electrocoagulation and filtration, the water was prepared to such an extent that it could be treated by reverse osmosis (degree of purification approx. 99.9 %) (UBA 2020).

4.4.1.1.2. What happens to fire-run off water?

One stakeholder from Germany indicated, that PFAS-contaminated fire-run off waters mostly enter the environment (both via WWTP and directly) and (company-owned or municipal) WWTPs. Those who use chemical and physical treatment methods only are not suited to appropriately handle PFAS. In his opinion, a more suited way of handling the run-off water would be to collect it and store it in silos, where it can be treated. However, he observed this only in rare cases. Legally, in Germany, the run-off water after an incident is the responsibility of the company in which the fire occurred.

Based on an article by [REDACTED] three cases are to be distinguished when the fate of run-off water is to be characterised ([REDACTED] 2021):

1. If the fire event occurs on unsealed surfaces and/or grounds that do not have retention facilities or catchment areas for the extinguishing water, it must be assumed that the extinguishing water will infiltrate into the subsoil and possibly also into the groundwater (see Figure 6). Following infiltration, the contaminated soil material may have to be excavated and then disposed of (e.g. landfilled or incinerated), as shown in Figure 7 or the groundwater may have to be cleaned up over many years by means of a pump-and-treat measure (see Figure 7).
2. If the fire occurs on a paved area and the extinguishing water flows directly to the natural receiving water via the storm drain system, there is no possibility of intervention and the environmental impact is immediate. If, however, the water enters a sewage system, it might be possible to collect the PFAS-contaminated extinguishing water in the basin systems of the wastewater treatment plant. For this, the necessary space would have to be available, the "wave of pollutants" would have to be collected in a targeted manner and diverted into the buffer basins. If this is not possible - which is likely to be the more frequent case in practice - then it must be assumed that a significant share of the PFAS substances will pass through the wastewater treatment plants without any targeted treatment of these non-biodegradable substances.
3. Companies that are subject to the Extinguishing Water Retention Directive (LöRüRL) have bunding areas in which the extinguishing water can be temporarily stored. In the case of intermediate storage on site, various options can be selected for the subsequent handling of PFAS-contaminated extinguishing water.

extracted using a water well. The study of water flow in aquifers and the characterization of aquifers is called hydrogeology. See [here](#), accessed at 02.04.2021.

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- a. Transport of the extinguishing water in silo vehicles to off-site water treatment plants: The so-called CP plants (chemical-physical water treatment plants) are mostly plants that accept process waters from trade and industry. In many cases, pre-treatment is carried out via a neutralization step in order to feed the water influenced in this way for subsequent treatment in the public wastewater system. As a rule, such plants do not have a purposefully equipped process stage for the treatment of PFAS. Under such marginal conditions, a noticeable reduction of the PFAS load cannot be assumed.
- b. Transport of the extinguishing water in silo vehicles to incineration plants: domestic waste incineration plants (850°C), and hazardous waste or high-temperature incineration plants (1,100°C).
- c. On-site treatment of firefighting water with activated carbon (GAC). Theoretically conceivable and already implemented in some practical cases is the use of large-volume activated carbon filters for the treatment of PFAS -contaminated firefighting water. Depending on the respective PFAS contamination and the so-called organic and inorganic background contamination of the extinguishing water, it may not be possible to achieve the treatment objective at all or the costs resulting from the treatment may assume considerable dimensions.
- d. On-site treatment with the PerfluorAd process, in order to enable on-site treatment of PFAS -contaminated extinguishing water and also the risk-free use of activated carbon for such and other applications, the PerfluorAd process was developed, which significantly reduces the content of PFAS as a pre-treatment stage, so that downstream process stages are significantly relieved and costs are reduced.

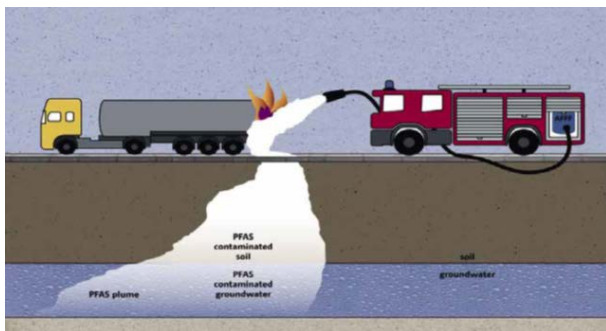


Figure 8: Outline of the entry of firefighting water into the subsurface if no retention facilities are available taken from ([REDACTED] 2021).

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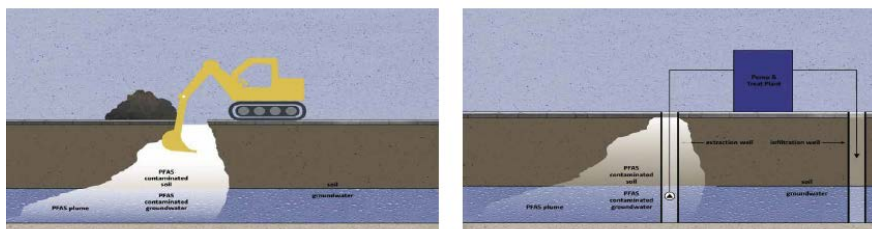


Figure 9: On the left, a representation of a soil excavation after successful infiltration of extinguishing water into the subsoil. On the right the pump and treat procedure is shown ([REDACTED] 2021).

Another stakeholder from Germany indicated that there is awareness about PFAS-contamination and that the water is treated with adequate responsibility. In Bavaria (and also Germany in general) fire water-containment measures are in place that need to follow the “Löschwasser-Rückhalte-Richtlinie” (LöRüRL in english: “Extinguishing Water Retention Guideline”, an English translation is not available). According to his knowledge the containment based on this guideline works (e.g. in industry plants), however, burning incidents involving large fires at facilities that are not covered by LöRüRL are more problematic. As an example, he named scrap tire storages (LfU-Gierig-Interview 2021).

A stakeholder from the UK (LASTFIRE) informed that during/after fires the water run off containment has a lower priority than other concerns, at least this has been the case historically. However, adequate containment is possible in an industrial context but not followed in reality or not easy/cost effective to implement fully. In general, the containment of the water is not a problem for smaller fires, where the quantity of water is small, but can be for big fires. This is due to the fact, that the bunding might fail due to the high amount of water, or the bunding may not be sized to take account of the large amounts of water required. For the successful containment of PFAS-contaminated fire-run off waters the type and architecture of bunding areas is of highest importance and should be based on the amount of foam and water (e.g. in fire-fighting ponds) stored in the facility or the amount of fire and water required for a particular scenario (this information should be retained in the site emergency response plan). Today, the size of bunding area is typically calculated to have a holding capacity of 110 % of the largest tank, or where there are multiple tanks in a single bund 25 % of the total capacity of the tanks, whichever is the greater. There are primary, secondary, and tertiary bunding types. The primary containment is the tank itself. The secondary containment is the bund and the tertiary containment is beyond the bund but is designed to either contain a spill or direct the flow to a designed catchment area where it can be managed. Some of LASTFIRE’s members have taken adequate measures to prevent overflow of water, by having tertiary containment – often following reviews from the Buncefield incident. For jetty areas, the containment is even harder, and water would usually go nowadays directly to the sea.

Another stakeholder from Germany explained that a complete containment of PFAS-containing run-off water is not in line with his real-life experience. In more detail, he explained that most of the run-off water is forfeit during the operations. Further, the stakeholder explained that there is almost always contamination of soil and water (DUS-Valentin-Interview 2021).

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4.4.1.1.3. PFAS-contents of PFAS-based AFFF and what can be measured

Safety data sheets of PFAS-based AFFF often indicate a content of <5 % for fluorosurfactants. According to (Wood et al. 2020) this number can be further narrowed to a concentration range of 2-3 %. In practice, the foam gets further diluted in concentrations between 1 and 6 % (mostly in 1 %, 3 %, and 6 %).

In a very recent publication by (██████ 2020) it is stated, that for waters with an undefined PFAS composition, as is to be assumed especially when using current AFFF foaming agents, an evaluation of the water load as well as the achievable cleaning results is not possible if only the quantifiable individual PFAS are evaluated. Held & Reinhard assume that AFFF foaming agents contain hundreds of precursor substances which include approx. 40 PFAS classes (Barzen-Hanson et al. 2017) and are highly complex and difficult to determine by classical analytical methods (Th. Held & Reinhard 2016). However, the precursors in such complex mixtures can be assessed by the Total Oxidisable Precursor (TOP) Assay (Mumtaz et al. 2019).

In the same publication (██████ 2020), the composition of fire extinguishing water has been analysed using an exemplary product (not further specified) and various PFAS quantification techniques. In Figure 8 the results of this analysis are shown.

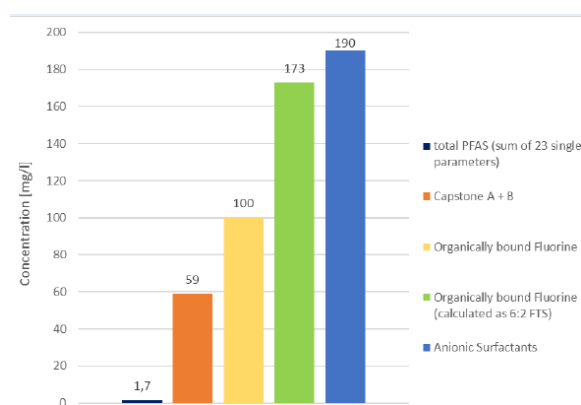


Figure 10: PFAS-contents of a 1% AFFF Premix, measured using different analytical techniques.

As shown in Figure 8, based on the analysis of 23 individual PFAS substances, as can be determined from parameter lists currently available on the market²¹⁹, the foam had a total content of only 1.7 mg/l PFAS. It should be noted that precursor substances such as Capstone A and Capstone B are not yet included as parameters in the standard lists of environmental laboratories. In the example shown, these PFASs, which are often not yet quantifiable by measurement technology, have a concentration of 59 mg/l alone, i.e. these substances are almost 35 times higher in concentration than the individual PFAS compounds that are

²¹⁹ DIN 38407e42 (status March 2011) served as the basis for the determination of PFASs. Methods using high-performance liquid chromatography and mass spectrometric detection (HPLC-MS/MS) after solid-liquid extraction (F42). With a simple matrix, determination limits of 10 ng/l can be achieved with this method for the individual congeners. However, in the case of complex matrix loads, the determination limits are often increased to several 100 ng/l.

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quantified by PFAS standard analysis in laboratories. In order to address the total content of fluorine-organic substance in complex contaminated waters, the organically bound fluorine was therefore used as an additional parameter for PFAS-contaminated waters that were contaminated due to exposure to AFFF foams. In the example in Fig. 3, the concentration of organically bound fluorine is 100 mg/l. Assuming that the average chain length and structure of the PFAS structures contained in current AFFF foams are significantly similar to the structure of the 6:2 FTS (H4PFOS), a hypothetical total PFAS concentration of 173 mg/l can be calculated.

The hypothetical total concentration of PFAS leads, on the basis of the example shown to the conclusion, that the fluoro-organic substances in the water that cannot be detected as PFAS single substances can be a factor of 100 higher (or more) than actually measured PFAS by single substance analysis. This knowledge leads to the need to evaluate PFAS that are not known or quantifiable as single substances by sum parameters. However (██████████ 2020), there is currently no normative standard for this.

The above described results by ██████████ (2020) show, that there is an ongoing uncertainty about PFAS-substances in AFFF. Based on stakeholder input in the context of this project, it can be stated that PFAS substances based on <C6-chemistry have never been used as an active ingredient for firefighting foams, as the chemistry is not suitable. <C6-substances are unintended by-products of the synthesis process (telomerization process) (FFFC-Interview 2021).

4.4.1.1.4. When does clean mean clean?

Stakeholders have been indicated that there are uncertainties about what level are achievable when the success of cleaning procedures is to be judged.

- Concerning the wording: One stakeholder made the point that “decontamination” is to be distinguished from “cleaning”. Cleaning needs to be done when one foam type is replaced by another (e.g. PFAS-based to PFAS-based).
- Concerned about remaining PFAS-levels, ██████████ made the statement that by replacing the AFFF foam with a “truly” fluorine-free foam, there is already a positive effect for the environment. Also, if the PFAS-contaminated equipment of the fire departments would then be cleaned professionally in the course of this and the PFAS contamination remaining in the system were thus cleaned by 90, 95, possibly even 99 to 100%, this would be already a great accomplishment. But to prescribe a cleaning success of 100% bindingly, ██████████ considers as not goal-leading (██████████ Interview 2021).
- The same stakeholder also raised that fire extinguishing systems do not release foams permanently. Only at incidents or trips, PFAS-foams are emitted. This happens, in general, every 30-40 years per fire extinguishing system (██████████ Interview 2021).
- Judged from the reported remaining PFAS-levels, it can be observed that a variety of PFAS-determination techniques is used. There are methods which concentrate on single PFAS-substances and also sum parameters are used.
- One stakeholder from Australia, indicated that setting cleanout standards for fixed foam systems and fire appliances was a concern in the Queensland foam Policy development stage as there were almost no precedents available. The primary issue was limiting cross-contamination of new foam put into existing systems from residues. From industry inputs and existing limits for foam concentrates we arrived at limits for PFOS + PFHxS in foams of 10mg/kg (UK and EU limits at the time) and 50mg/kg for other long-chain PFAS (by TOP Assay as F) as being practical and achievable for manufacturers and end users in systems and foam manufacture. It is not practical to set goals for cleanout based on wash-water concentrations as every system is different. Since then, experience has shown that much lower levels can be achieved. We have not set any recommended methods as each system is different in age, foam and components but we initially suggested that combinations of aggressive

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surfactants, solvents such as glycol ethers and methanol may prove to be effective based on foam compositions and lab equipment cleaning techniques. Various fire engineer services have demonstrated that cleanout is achievable to those and lower levels depending on the circumstances, each has their own proprietary process and agents (Holmes 2020).

4.5. Non-destructive: Granular activated carbon (GAC) treatment

4.5.1.1.1. Background

The treatment of PFAS-contaminated water (or PFAS-containing AFFF) with activated carbon is based on the adsorption of a molecule on the surface of the activated carbon. This is facilitated by van-der-Waals interactions between the activated carbon and the target molecule. As these interactions can occur between any two molecules a broad variety of compounds may be adsorbed, including some PFAS (mainly PFOS, this will be discussed in the technical performance sub chapter). This means that if a high concentration of other organic substances is present, the activated carbon becomes quickly fully loaded and unable to adsorb more molecules. As such the PFAS compete with other contaminants for the adsorption on the activated carbon surface. The carbon is typically supplied as powdered activated carbon or as granulated activated carbon (GAC) carbon (Analytik 2019; US-EPA 2020a).

For the treatment with activated carbon the to-be-treated water is first filtered by a sand or multi-layered filter to filter out any non-solved contaminants and then sent through one or multiple activated carbon filters. By doing so the solved contaminants including PFAS adsorb to and saturate the surface of the activated carbon. If enough filters are installed in succession virtually all contaminants can be adsorbed out of the solution.

The spent active carbon is either sent to reactivation or high temperature incineration. During reactivation high temperatures are used to thermally desorb the contaminants, which allows the reuse of the activated carbon. For this the spent carbon is heated up to 800 °C for around 35 – 120 minutes. The conditions hereby range from a pyrolysis atmosphere (no oxygen) to a mild oxidative atmosphere (low oxygen) in order to restore the original carbon pore-structure. An afterburner with temperatures between 880 – 1,316 °C and a minimum residence time of 1 second is used to achieve a destruction rate of >99.99 % of the remaining contaminants. To what extent PFAS are destroyed under these conditions needs to be evaluated. Not all spent activated carbon can be reactivated. If the levels of organic halogens or metals is too high or the base carbon type is not suitable, a reactivation may not be possible. Alternatively, the activated carbon can also be incinerated via high temperature incineration. A reuse is therefore not possible (US-EPA 2020a)

4.5.1.1.2. Technical performance

According to the ITRC-guideline, individual PFAS have different GAC loading capacities and corresponding breakthrough times (often defined as the number of bed volumes treated prior to detection in the effluent) (Eschauzier et al. 2012). GAC removal capacity for PFOS is greater than PFOA, but both can be effectively removed (McCleaf et al. 2017). In general, shorter chain PFAS have lower GAC loading capacities and faster breakthrough times but could be effectively treated if changeout frequency is increased.

There are currently no published studies on the effectiveness of GAC in removing cationic, zwitterionic, and anionic precursor compounds; however, a recent theoretical study suggests some precursors are unlikely to be effectively removed by GAC ((Xiao et al. 2017) cited in (Ross et al. 2018)).

Furthermore, also the organic background of the water needs to be considered as this also lowers the efficacy as other organic substances can also bind to the GAC (Ross et al. 2018). Under optimal conditions i.e. using activated carbon with a high capacity potential, strongly absorbing PFAS, few competitive contaminants, low organic levels and a high concentration in the to-be-treated water loading rates of up to 0.1% can be achieved which corresponds to 1 g/kg of PFAS on the activated carbon. More realistic loading rates lie between 0,004 – 0,01 % (Analytik 2019; LANUV 2009; Maga et al. 2021a).

According to Concawe, the US-EPA Health Advisory level for PFOS and PFOA (0.07 µg/L) as well as the proposed EU drinking water threshold of 0.1 µg/L for individual PFAS components (0.5 µg/L for total PFAS) are achievable by activated carbon treatment, but may require the use of several beds in series (Concawe 2020). A PFAS removal rate of 99.9% has been

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documented for a fire-extinguishing water treated by granular activated carbon. However, this elimination rate has been determined after a very short operation time. The maximum operation time until material exhaustion has not been reported. While higher influent concentrations would lead to higher loadings of PFAS onto the carbon, the presence of numerous co-contaminants may lead to a reduction in the loading due to competitive sorption.

According to ITRC, most GAC full-scale treatment system case studies to date are based on treatment of PFOA and PFOS in the impacted drinking water sources. As such, limited information is available regarding the treatment of other PFAS. The full-scale drinking water systems demonstrate that PFOA and PFOS can be removed to below analytical detection limits until breakthrough occurs. Treatment of groundwater impacted with PFAS from an AFFF release area contaminated with PFAS such as fire training areas (FTAs) may require complex pre-treatment and more frequent change-outs (higher influent concentrations compared to influent for drinking water treatment systems) and higher operation and maintenance (O&M) costs.

4.5.1.1.3. Side products and emissions

The adsorption removal mechanism of GAC is not expected to transform precursors (for example, telomer alcohols) to terminal PFAS as would be the case when using advanced oxidation/reduction technology (ITRC 2020).

Emission may however arise when the GAC is reactivated or incinerated. For emissions from incineration see chapter 3.2.1.

During the reactivation of GAC pyrolysis and gasification conditions are applied to restore the surface of the carbon. Hereby the carbon is heated to temperatures around 800 °C under either a non-reactive (inert; no oxygen; pyrolysis) to mildly oxidising (steam and CO₂; gasification) atmosphere. As the destruction of PFAS is achieved by completely oxidising all carbons of the PFAS molecule via the reaction with oxygen these processes may lead to different products. Especially under pyrolysis conditions where no oxygen is present small chain PFAS compounds and fluorinated gases may be formed.

Typically, the facilities are equipped with afterburners operating between 885 – 1,316 °C with a residence time of at least 1 seconds where all remaining contaminants are ought to be destroyed. As the formation of short chain fluorinated gases under the aforementioned conditions is likely it needs to be assessed whether the afterburner conditions can adequately destroy these compounds (US-EPA 2020b).

According to (Ross et al. 2018) research indicates that some PFAAs can be destroyed on GAC surfaces at temperatures as low as 700 °C during the reactivation process. Destruction of volatilized PFAAs (in the air phase) requires 1,100 °C; however, thermal reactivation kilns normally include after-burners for air pollution control, and these usually operate at temperatures above 1,100 °C. Thus, a typical thermal reactivation process (800 °C to 1,000 °C reactivation temperature, plus an afterburner) seems to be well-suited for reactivating GAC that has exceeded its adsorption capacity for PFAAs. However, testing was not performed considering the wider range of PFASs, such as higher molecular weight (less volatile), polyfluorinated precursors reported to be associated with AFFF formulations. Data on whether these temperatures destroy all PFASs, including precursors potentially adsorbed to GAC, appears to be lacking.

One stakeholder indicated that the activated carbon is mostly imported from China, used, and then re-activated in the EU. Reactivation is more profitable than buying virgin products. To his knowledge, the reactivation takes place at temperatures around 600 °C, which could lead to incomplete destruction of PFAS and the formation of PFAS-side products. This could also lead to atmospheric deposition and contamination of soil and water (██████████ Interview 2021).

Availability across the EU

Temporary and permanent GAC systems can be rapidly deployed and require minimal operator attention, if intensive pre-treatment is not needed (ITRC 2020). Currently, GAC is a

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widely used water treatment technology for the removal of PFOS and PFOA, and, to a lesser extent, other PFAAs from water. Based on stakeholder input there is knowledge, that the activated carbon is mostly imported from China, used, and then re-activated in the EU. Reactivation is more profitable than buying virgin products (Interview 2021).

4.5.1.1.4. Costs

According to a recent report by the German Umweltbundesamt and Arcadis, the cost for the remediation can vary considerably (UBA 2020), for example from 0.40 - 2.30 €/m³ in a pilot test. In another case, costs of < 0.06 €/m³ to 0.68 €/m³ were found. Another study indicates the costs of sorption on activated carbon in the range of 0.24 €/m³ (10 µg/L PFAS in raw water) to 0.78 € (100 µg/L PFAS in raw water) (Q = 25 m³/h). This includes electrical energy, maintenance, and activated carbon consumption. Based on these numbers an average cost of 1.25 € per m³ PFAS-contaminated water is assumed, as calculated as the average of the respective highest reported cost value.

4.5.1.1.5. Additional information and available case studies

Maga et al 2020 published a life cycle assessment comparing three treatment options for spent AFFF. In this study the authors compared the incineration, the treatment with granulated activated carbon and the treatment with PerfluorAd and subsequent activated carbon with one another. The focus was on the environmental impacts of the individual treatment methods e.g. greenhouse gas potential, resource depletion and emission of ionising radiation. In this study the treatment with GAC showed adequate results. GAC treatment emits large amounts of ionising radiation as most GAC is sourced from fossil coal deposits (Analytik 2019). Additionally GAC treatment can deplete the ozone layer as during the disposal of GAC many short chain side products may arise (Maga et al. 2021a).

4.6. Non-destructive: Ion exchange (IX)

According to Concawe, no references were available for IEX treatment of fire-extinguishing waters or water with PFAS concentrations within the range of fire-extinguishing waters have been reported (Concawe 2020). However, as IX might be used as a secondary treatment after for example PerfluorAd, this method is shortly introduced as it is next to GAC the most established method.

4.6.1.1.1. Background

According to ITRC, IX is an effective sorbent for other contaminants and has historically been used for a variety of water treatment applications (for example, nitrate, perchlorate, arsenic). To date, IX for PFAS removal from water is limited to ex situ applications (ITRC 2020). IX resin options for removal of PFAS include single-use and regenerable resins. Single-use resins are used until breakthrough occurs at a pre-established threshold and are then removed from the vessel and currently disposed of by high temperature incineration or by landfilling, where permitted. Regenerable resins are used until breakthrough but are then regenerated on site using a regenerant solution capable of returning the full exchange capacity to the resin. Temporary and permanent IX systems can be rapidly deployed.

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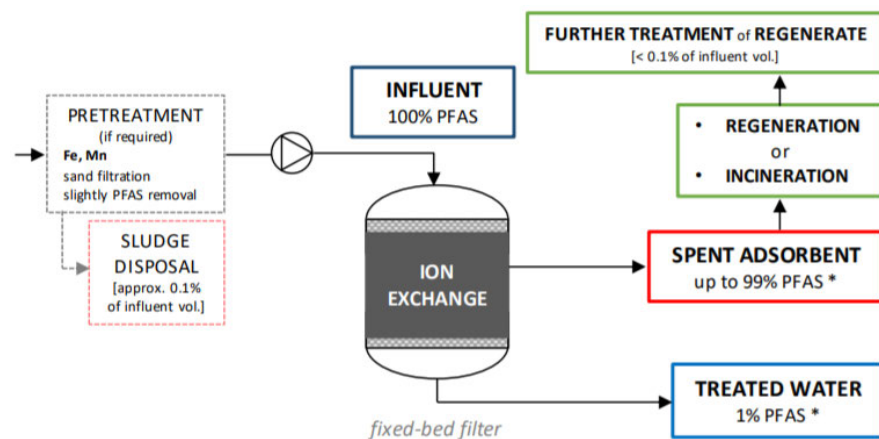


Figure 11: PFAS flow diagram for adsorption filtration with IEX /taken from (Concawe 2020)).

There is a variety of IX resins available at the market. According to Dupont, the polymer matrix of an ion exchange resin generally falls into two categories – gel or macroporous. A number of resins, both gel and macroporous type, developed for this market have similar chemical properties to allow for improved PFAS selectivity (Dupont 2020).

4.6.1.1.2. Technical performance

According to the Concawe report and the therein cited literature, various anion exchangers have been identified with a higher adsorption capacity towards PFAS than activated carbons. The selective PFAS removal from contaminated waters by anion exchange works at both high PFAS concentrations of hundreds of mg/L as well as at low concentrations in the ng/L and µg/L range. Similar to the adsorption onto activated carbon, the affinity of per- and polyfluoroalkyl sulfonates (PFSA) to ion exchangers is higher than those of per- and polyfluoroalkyl carboxylates (PFCA), and long-chain PFAS are absorbed preferably compared to short-chain PFAS. Treating groundwater, operation times up to 80,000 to 150,000 BV can be reached for the elimination of long-chain PFAS. However, retention of short-chain PFAS is lower and breakthrough starts at 10,000 to 30,000 BV. For ion exchange, the sorption kinetics for PFAS are relatively slow but it is still faster than adsorption on activated carbon. Fast sorption kinetics will result in a smaller filter geometry and therefore less investment costs. US and EU threshold value for PFOS and PFOA (0.07 to 0.1 µg/L) are achievable using ion exchange resins.

4.6.1.1.3. Availability across the EU

According to ITRC, Ion exchange technology has been used in the US since the late 1930s for common water treatment processes like softening, demineralization, and selective contaminant removal. The development and use of selective resins for PFAS removal is relatively new but already well established. As of 2019, a limited number of regenerable IX systems have been installed in full-scale applications after successful pilot testing. Collection of data on longer term treatment and on-site regeneration of the IX resin is ongoing at a case study site.

Also, according to UBA, groundwater purification by means of ion exchangers is a common and widely used process. However, they have only rarely been used in Germany for the remediation of PFAS contamination. Accordingly, only limited experience is available from remediation on a technical scale. Due to the growing experience with this process, especially

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in Australia, it can be expected that ion exchangers will be used more frequently in the future (UBA 2020).

4.6.1.1.4. Side products and emission

In single-use applications, the IEX resins are loaded with the PFAS and must be disposed for final destruction using high temperature incineration in HWI. It is noted that the IEX resin vendors normally cooperate with specialist licensed waste handling companies that can organize the resin disposal (ITRC 2020). Treatment costs might be lower when regenerating and re-using the ion exchanger resin. The binding of PFAS to ion exchangers is not only affected by the intended electrostatic interactions, but also by hydrophobic interactions with the backbone of the ion exchanger (UBA 2020). Therefore, a sufficient regeneration the use of an organic solvent such as methanol or ethanol is required adding to the complexity and cost. Also, these solvents would also need to be treated (ITRC 2020).

4.6.1.1.5. Costs

The material costs of ion exchangers are about 12 €/kg and thus about 3 times higher than the average costs of activated carbon. Using the above information, it is estimated that groundwater treatment costs for long-chain PFAS of 0.05 to 0.1 € per m³ PFAS-contaminated water and for short-chain PFAS of 0.25 to 0.8 € per m³ PFAS-contaminated water respectively (Concawe 2020). Based on these numbers an average cost of 0.45 € per m³ PFAS-contaminated water (for both long- and short-chain PFAS) is assumed.

According to UBA, the total costs for ion exchangers compete with the costs for the sorption of the PFAS on activated carbon. Even if the activated carbon process is less efficient and requires more sorption material, in the end it could be cheaper (UBA 2020). However, there are no actual costs cited.

4.6.1.1.6. Additional information and available case studies

Treatment of PFAS with anion exchange resins has been demonstrated in numerous small- and large-scale applications. The following collection is a sample of published examples for PFAS removal using ion exchange resin.

4.7. Non-destructive: Precipitation – PerfluorAd

4.7.1.1.1. Background

The principle behind the precipitation of PFAS is to introduce a molecule which can bind to the charged moiety (e.g. sulfonic acids). By doing so the PFAS molecule interacts with added cations via electrostatic and intermolecular interaction and becomes insoluble and as such precipitates. The affinity to bind to this cation depends on many factors such as molar mass, functional groups, amount of charges etc. The precipitate can be mechanically filtered and as such be removed from the PFAS solution.

Umwelttechnologie GmbH is a specialist supplier of systems, technologies, products and services for the remediation, water filtration and landfill leachate sectors located in Essen, Germany.

together with the Fraunhofer-Institute UMSICHT developed a technology based on this principle called PerfluorAd® (in the following called PerfluorAd). At the homepage of GmbH (available in German and English) a lot of information is accessible. In addition to that, the technique is also described in scientific literature and has been also interviewed in the context of this project.

Based on the information provided by during the interview, the technique is used mainly for highly PFAS-contaminated water (also with an optional organic background level).

Highly PFAS-contaminated water means here values in the higher range of µg/l. Containing PFAS can be removed of PFAS with efficacies of 80-90 % and can be then subjected to further treatment like GAC and ion exchange. In Figure 10 a schematic overview of an GAC with PerfluorAd Pre-treatment stage is given.

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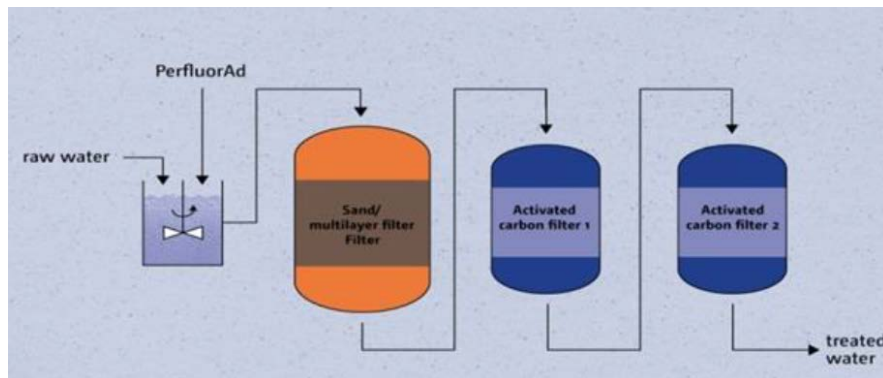


Figure 12: Schematic overview of an Activated Carbon Plant (GAC) with PerfluorAd Pre-treatment Stage (taken from [REDACTED])

Highly PFAS-contaminated water can be for example fire run-off water or water from PFAS-related cleaning from technical equipment.

According to the stakeholder, low PFAS-contaminated water is not the primary subject to PerfluorAd. Therefore, most groundwater contamination is not suited to be treated by PerfluorAd. GAC and techniques using ion exchanger (and combinations) are better suited. Also, AFFF-concentrates are not suited for PerfluorAd and would, theoretically, need to be diluted. The concentration of PFAS- and non-fluoride organic surfactants would be too high. Direct Incineration is the preferred option ([REDACTED] Interview 2021).

PerfluorAd changes the solution equilibrium of PFAS in water. The reaction modes are precipitation and flocculation, mainly based on ionic interaction. The reaction is non-destructive meaning that the chemical composition of the PFAS substance is not changed ([REDACTED] Interview 2021). In addition to PFAS, PerfluorAd also removes other non-fluorinated surfactants. Those are used together with PFAS-surfactants in AFFF-products ([REDACTED] Interview 2021).

For this a cationic compound mix consisting of different di- or triethanolamine quats (TEA) based vegetable fatty acids is added to the PFAS-containing water. These fatty acids have the advantage of being biodegradable and synthesised from sustainable sources (Maga et al. 2021b).

The charged PFAS molecules interact with the positively charged "head" of the ethanolamine quats and precipitate (see Figure 11). The combination ratio thereby is not always 1:1 (Maga et al. 2021b).

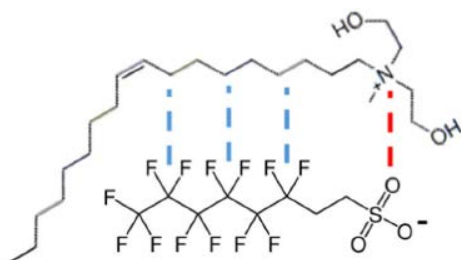


Figure 13: The interaction between the PFAS molecule (below shown for the example of 6:2 FTS) and the added cation (taken from Maga et al 2020)

Depending on the PFAS-concentration precipitant is added and is as such scalable. After precipitation the precipitated flakes can be filtered out (sand filter) and sent to high temperature incineration.

4.7.1.1.2. Technical performance

In general, the removal efficiency of PerfluorAd is depending on the chain length and the polarity of the PFAS. The long-chain sulfonic acids (PFSA) show the best removal efficacy. The same effect is also observed when using GAC (██████████ Interview 2021). According to the ██████████ the treatment with PerfluorAd can effectively remove a wide range of PFAS with an efficiency of up to 99.3 % for PFSA and PFCA. Other PFAS such as Capstone A and B²²⁰ only reach removal efficiency of 81 %. Substances like 6:2 fluorotelomer sulfonate (6:2 FTS) can reach a removal efficiency of 97 % and other non-PFAS surfactants can even be removed with up to 99,8 % efficiency (██████████ 2020). The dosage ranges from 25 mg/L to 2 g/L and can be optimised for different PFAS concentrations and the water matrix to obtain higher elimination rates. In Figure 12 residual concentration total PFASs [mg/l] and right) elimination rate total PFASs [%] for 1% AFFF premix after addition of PerfluorAd are highlighted.

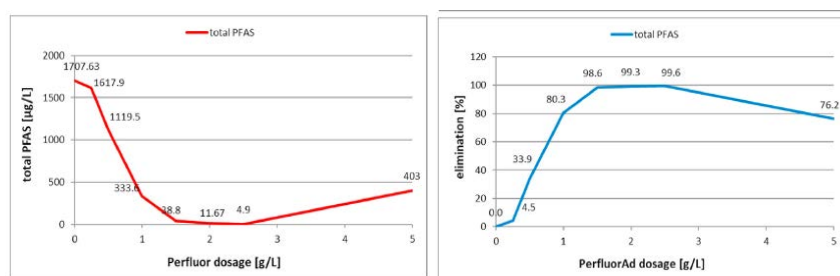


Figure 26: left) Residual concentration total PFASs [mg/l] and right) elimination rate total PFASs [%] for 1% AFFF premix after addition of PerfluorAd® (taken from (██████████ 2020))

Principally, it is designed for treating water containing PFAS concentrations greater than 0.3 µg/L (Ross et al. 2018). PerfluorAd is used as the first PFAS treatment step within a treatment train. Thus, this process is not intended to achieve final target threshold values (e. g. 0.1 µg/L) as it is recognised that a further polishing step is required (Ross et al. 2018). The added PerfluorAd is specific for charged molecules so that in a recent experiment with diluted AFFF only 1.1 % of the dissolved organic carbon was precipitated. In this experiment 99.3 % of the total PFAS (23 substance) could be removed with the PerfluorAd treatment. 80.5 % of the Capstones and 87 % of the organically bound fluorine (precursors) were also removed with this process (██████████ 2020). In Figure 13 elimination rates for different parameters [%] at an optimal dosing rate of 2.0 g/l are shown.

²²⁰According to UBA, The AFFF fire-extinguishing foams of products frequently used in Germany contain, in addition to some perfluorocarboxylic and sulfonic acids, the compound 6:2 FTS in low concentrations and, above all, in high proportions the two betaines (CAS: 80475-32-7 and 34455-29-3).

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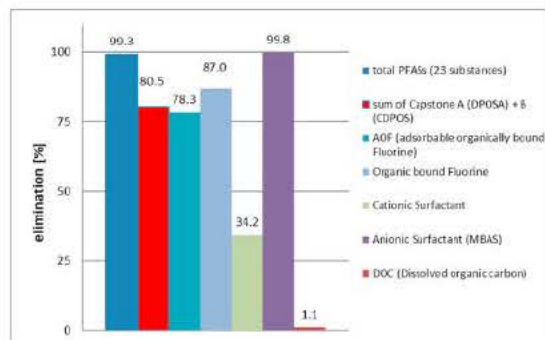


Figure 15: Elimination rates for different parameters [%] at an optimal dosing rate of 2.0 g/l PerfluorAd for this application (taken from [REDACTED] 2020)).

The time to precipitate the containing PFAS ranges from 10 – 30 minutes depending on the water matrix and containing pollutants (WVF 2019).

These values represent optimal removal efficiencies and are however dependent on the correct amount of PerfluorAd based on the PFAS-concentration in the solution. Too high or too low amounts of PerfluorAd can negatively affect the efficiency of the process. Additionally, the precipitate shows a higher selectivity toward longer chain PFAS and has lower efficiencies for short chain PFAS ([REDACTED] 2020; Maga et al. 2021a).

The precipitate (sludge) can then be treated by high temperature incineration. The advantage with this is, that only the precipitated PFAS including cationic counterpart need to be incinerated instead of incineration the whole AFFF solution/ run-off water, including its water content. This decrease in volume of PFAS-contaminated water is more economically.

4.7.1.1.3. Side products and emissions

The precipitation techniques cannot destroy or mineralise any PFAS. It instead enables the removal of the PFAS from a watery solution by precipitation. According to [REDACTED] [REDACTED] measurements/ calculations of mass balance show that there are no side reactions and/or loss of reaction partners (PFAS & PerfluorAd substance).

The incineration of the precipitate or spent activated carbon may however lead to the formation of products of incomplete combustion. For these products see chapter 3.2.1.

4.7.1.1.4. Availability across the EU

The active ingredient is produced in the EU and according to [REDACTED] [REDACTED] there are no limitations regarding its availability.

4.7.1.1.5. Costs

The substance costs around 10-25 €/kg, depending on the purchased quantity. However, the active ingredient is not the only limitation criteria. According to [REDACTED] [REDACTED] the costs are more related to the manpower and material (including for example the activated carbon). For the entire PerfluorAd®/activated carbon system, operating costs (depending on the activated carbon used) amounted to < 0.055 - 0.68 € per m³ of treated water, of which approx. 0.04 €/m³ is attributable to the PerfluorAd® requirement (UBA 2020).

4.7.1.1.6. Additional information and available case studies

- Maga et al 2020 published a life cycle assessment comparing three treatment options for spent AFFF. In this study the authors compared (1) the incineration, (2) the treatment with granulated activated carbon and (3) the treatment with PerfluorAd and subsequent activated carbon. The focus was on the environmental impacts of the individual treatment methods e.g. greenhouse gas potential, resource depletion and emission of ionising radiation. In this study the PerfluorAd technology with subsequent active carbon treatment

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performed the best of the analysed treatment methods in nearly all investigated impact categories.

- Remediation of PFAS-contaminated groundwater under the Nuremberg Airport Fire Department's firefighting training area: the groundwater underneath the firefighting training area at Nuremberg Airport has been contaminated by PFAS due to the use of fluorine-containing firefighting agents over many years. A mobile groundwater remediation system based on the PerfluorAd principle was made available, thereby remediating the groundwater. The initial PFAS concentration in the groundwater was more than 600 µg/l for the sum of the PFAS. With the PerfluorAd treatment alone, the PFAS load is reduced to 41 µg/l (i.e., by 93.5%). After the final activated carbon stage (GAC for granulated activated carbon), PFAS contamination is no longer measurable.

4.8. Non-destructive: Foam fractionation and ozofractionation

4.8.1.1.1. Background

Foam fractionation and ozofractionation are technologies that take advantage of the foam-forming properties of PFAS. The process selectively separates PFAS from water by injecting compressed air (foam fractionation) or ozone (ozone fractionation) into the water in the form of air bubbles. PFAS surfactants adhere to the bubble walls and are thus transported to the surface. The PFAS-enriched foam is collected at the water surface for further destruction-based treatment. The treated water typically goes through a polishing step (e.g. GAC)(Concawe 2020).

In the case of ozofractionation, precursors (also PFAS) are transformed to the perfluoroalkyl carboxylic (PFCA) and sulfonic acids (PFSA). Those PFAS remain in the system and are concentrated and discharged in the gas bubbles. Ozone can also promote the degradation of accompanying organic contaminants. Due to the small size of the gas bubbles (diameter < 200 µm), the total mass of the ozone bubbles has a large gas-water interface. At the surface of the water phase in the reactor, the PFAS are therefore concentrated in a small, separable volume.

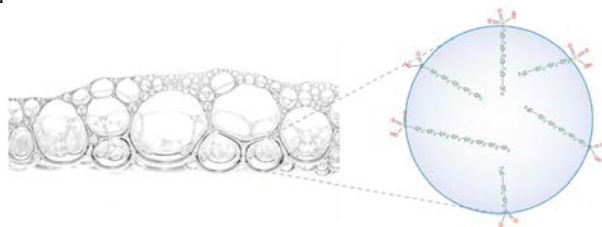


Figure 16: Illustrative Concept of foam fractionation (taken from (UBA 2020))

4.8.1.1.2. Technical performance

On a technical scale (Figure 7), the ozone fractionation consists of several reactors connected in series with continuous flow, into which ozone is introduced as bubbles. The PFAS concentrate as highly PFAS-contaminated foam on the liquid surface of the reactors. From the surface the bubbles get extracted via vacuum, further concentrated and can be fed to a further destructive treatment. The volume of the concentrate is 0.5 – 2 % of the inflow volume. According to literature the ozofractionation process alone mostly cannot achieve required PFAS concentrations and a supplementary process stage is needed. The gas phase is released into the atmosphere via an activated carbon absorber. As a rule, the last process stage of the water phase is an activated carbon absorber, with which the residues of the PFAS that have not yet been removed can be retained in order to achieve the required discharge values. If impurities are present, the process can be extended by further process stages if required.

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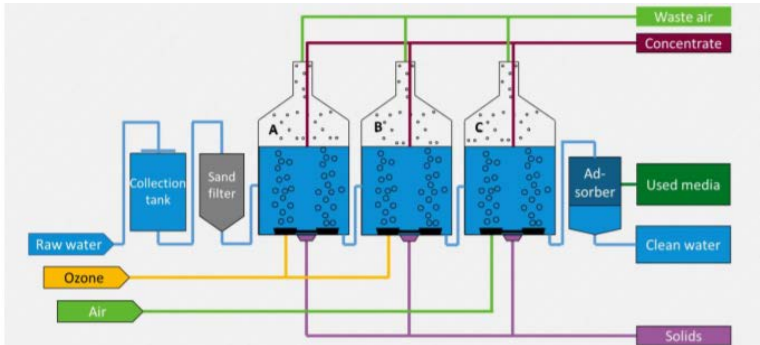


Figure 17: Ozofractionation process concept (taken from (UBA 2020)).

For long-chain PFAS such as PFOS and PFOA, a purification level of 99.9 % has been achieved (Evocra 2017). For the ozofractionation stages alone, a purification level of > 98.7 % was always achieved. The short-chain PFAS can be removed better with ozone than with air (Ross et al. 2018). The results further indicate that, for PFAS concentration levels below 0.3 µg/L, high elimination down to a few ng/L could still be achieved (Evocra 2017). Similar to the precipitation with PerfluorAd, ozonofraction has an economic advantage at very high PFAS concentrations (which would be the case in PFAS-contaminated fire run off water and water from cleaning processes). The process is not only suitable for the treatment of water, but also for sludge with a solids content of up to 20 %. The fractionation reactors separate the liquid from the solid phase. Small particles get into the foam concentrate and are removed with it. Coarse particles sediment at the bottom of the reactors and are removed there. Unlike many other processes, the degradation of an accompanying organic contamination does not significantly affect the PFAS removal level. The disadvantage is that a waste product (PFAS zone foam concentrate) is produced which must be disposed of separately (UBA 2020).

Based on desktop research, it seems that the ozone is introduced to the reaction by adding of "Arcadis Solvent V171". The liquid has the following hazard statements: H227 (combustible liquid), H319 (causes serious eye irritation), H336 (may cause drowsiness or dizziness) and AUH019 (May form explosive peroxides). AUH019 is an Australian-specific H-statement and equals the European EUH019 (also may form explosive peroxides).



Figure 18: Picture showing the GHS hazard statements of Arcadis solvent V171 (taken from a presentation of Arcadis at NEWEA, 2019 see [here](#)).

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Foam fractionation uses compressed air and is commercialized by the Australian company OPEC systems, allowing a continuous on-site treatment process in a containerized system. The treatment system is called Surface Active Foam Fractionation (SAFF). The operation mode of the system can be adjusted to manage a broad range of total detectable PFAS influent concentrations (0.1 to 100,000 µg/L). The residence time per reactor vessel ranges from 5 to 30 minutes. PFAS-enriched foam is removed with a vacuum extraction system (Concawe 2020).

According to the Concawe report and therein cited literature, for both methods, depending on influent concentrations, the US-EPA Health Advisory levels for PFOS and PFOA (0.07 µg/L) as well as the proposed EU drinking water threshold of 0.1 µg/L for individual PFAS compounds (0.5 µg/L for total PFAS) are achievable without polishing. However, both technologies usually include a final polishing step, resulting in removal efficiencies of 99.9% to 99.99%. Very high influent concentrations might be managed via a multi-stage fractionation process (Concawe 2020).

4.8.1.1.3. Side products and emission

Foam fractionation and ozofractionation are non-destructive techniques.

In the case of ozofractionation, the PFAS-ozone bubbles are drawn off (vacuum extraction) and further concentrated and can be fed to a further destructive treatment. The volume of the concentrate is 0.5 - 2 % of the inflow volume (UBA 2020).

4.8.1.1.4. Availability across the EU

According to UBA/Arcadis, the ozofractionation process has already been tested on a technical scale in Australia. According to the available documentation, the process appears to be ready for the market. However, as is the case with most newer technologies, there is a lack of supplier-independent studies to verify its effectiveness. The supplier in Australia is a company called Evocra²²¹, which signed a strategic exclusive agreement in 2019 with Arcadis. Based on research undertaken in this project, it seems that Arcadis promotes nowadays the usage of a V171 cleaning agent, which is most likely the same substances and related systems as the Evocra process.

Foam fractionation is not available on a technical scale. However, limited field trials show promising results (OPEC-Systems 2020).

4.8.1.1.5. Costs

Ozofractionation is a relatively complex technology whose operating costs are significantly higher than those of alternative market-ready technologies (e.g. GAC) but this cannot be assessed due to lacking data (UBA 2020).

4.8.1.1.6. Additional information and available case studies

The technique has been used in several cases in Australia and one in the UK, this involved (based on the results of the desktop search within this project):

- A large-scale implementation of ozofractionation at an airport in Australia using a NF unit for polishing to treat PFAS affected surface water and wastewater achieved a removal efficiency of 97% for the sum of 28 PFAS with inlet concentrations of 100 to 5,400 µg/L²²².
- Water remediation at a fire training site²²³
- Containing of 22,000 liters of escaped PFAS contaminated waste from a failed deluge system within an airport hangar²²⁴.

²²¹ See Evocra's internet site [here](#), last accessed 01.04.2021

²²² See site [here](#), last accessed 01.04.2021

²²³ See presentation [here](#), last accessed 01.04.2021

²²⁴ See presentation [here](#), last accessed 01.04.2021

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- Contamination stemming from an airport in the UK (Guernsey island)²²⁵
- US-Department of Defence (DoD) concerning the "Demonstration and Validation of Environmentally Sustainable Methods to Effectively Remove PFAS from Fire Suppression Systems"

4.9. Destructive approaches

4.9.1. Incineration

The details of PFAS-based incineration are explained in detail in chapter 3.2.1 (hazardous waste incinerators) and 3.2.2 (cement kilns). For the incineration of PFAS-contaminated water, the same information applies as in those chapters. However, as the concentration of PFAS-contaminated fire run off water and cleaning water are considerably lower, literature indicates that in some cases non-destructive techniques are used in order to lower the to be incinerated volume and related costs.

4.10. Conclusion on the Disposal of PFAS-contaminated (fire run off and cleaning) water

The following conclusions can be made for available disposal options for PFAS-contaminated (fire run off and cleaning) water:

- Fire run off and cleaning water are highly PFAS-contaminated compared to for example groundwater contaminations. Based on this not all available remediation techniques for groundwater can be used also for run off and cleaning water.
- GAC can be also used for all PFAS-contaminated for run off and cleaning water. However, the efficiency is lower for PFAAs (carboxylic acid) in general and short chain PFAS. For other PFAS (e.g. zwitterionic) no data is available. One stakeholder brought up that when GAC is reactivated (using 800 °C) PFAS could be emitted (Interview 2021).
- Ion exchange (IX) is generally suited for PFAS-contaminated run off and cleaning water. However, no case studies are available. Based on the type of PFAS various IX-matrices are available. IX is believed to be 4 times more expensive than GAC, when only the material is considered. According to UBA, the total costs for ion exchangers compete with the costs for the sorption of the PFAS on activated carbon. Even if the activated carbon process is less efficient and requires more sorption material, in the end it could be cheaper (UBA 2020). However, there are no actual costs cited.
- GAC and IX are generally based on column beds to which PFAS absorb. To achieve certain PFAS-levels several beds in series must be used. With both techniques proposed EU drinking water threshold of 0.1 µg/L (0.001 ppm) for individual PFAS components (0.5 µg/L for total PFAS) are achievable but may require the use of several beds in series. The material cost for GAC is around 0,41 – 3,68 €/kg. According to a recent report by the German Umweltbundesamt and Arcadis, the cost for the remediation can vary considerably (UBA 2020), for example from 0.40 - 2.30 €/m³ in a pilot test. In another case, costs of < 0.06 €/m³ to 0.68 €/m³ were found. Another study indicates the costs of sorption on activated carbon in the range of 0.24 €/m³ (10 µg/L PFAS in raw water) to 0.78 € (100 µg/L PFAS in raw water) (Q = 25 m³/h). This includes electrical energy, maintenance, and activated carbon consumption. Based on these numbers an average cost of 0,85 € per m³ PFAS-contaminated water is assumed, as calculated as the average of the respective cost values.

²²⁵ See presentation [here](#), last accessed 01.04.2021

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- For IX, material cost is about 12 €/kg and treatment costs for long-chain PFAS of 0.05 to 0.1 €/m³ and for short-chain PFAS of 0.25 to 0.8 €/m³ respectively. Based on these numbers an average cost of 0.45 € per m³ PFAS-contaminated water (for both long- and short-chain PFAS) is assumed.
- To minimize the load (and therefore costs) of GAC/IX, precipitating agents like PerfluorAd can be used. The active ingredient changes the solubility of PFAS. PFAS-PerfluorAd sludge can be incinerated. The water then is then further treated with GAC/IX (treatment train). For the entire PerfluorAd®/activated carbon system, operating costs (depending on the activated carbon used) amounted to < 0.055 - 0.68 € per m³ of treated water, of which approx. 0.04 €/m³ is attributable to the PerfluorAd® requirement.
- Ozonofraction uses the fact that PFAS remain the air-water interface and creates ozone-bubbles which are considerably smaller than regular air-bubbles. Bubbles then can be physically removed. The water then is then further treated with GAC/IX (treatment train). For PFAS concentration levels below 0.3 µg/L, high elimination down to a few ng/L could still be achieved. No information is available for the costs of this technique, however, ozonofraction is a complex technology whose operating costs are significantly higher than those of alternative market-ready technologies (e.g. GAC), but this cannot be assessed due to lacking data.
- PFAS-contaminated fire run off and cleaning water can also be directly subjected to incineration. The cost for the disposal of 1 liter of PFAS-based AFFF are currently in the range of 0.2-2 €/l (around 200-2000 €/m³), it can be assumed that the same costs apply to fire runoff water.
- Based on the available data, the direct incineration of PFAS-contaminated run-off water would be the most expensive disposal alternative (200-2000 €/m³). According to (UBA 2020) GAC and IX are comparable in costs (although material costs differ). For GAC an average cost of 0,85 € per m³ PFAS-contaminated water is assumed (three projects considered). For IX an average cost of 0.45 € per m³ PFAS-contaminated water (for both long- and short-chain PFAS) is assumed. Based on available data, the combination of PerfluorAd and GAC is the cheapest technique with an average reported cost of < 0.055 - 0.68 € per m³ of treated water, of which approx. 0.04 €/m³ is attributable to the PerfluorAd® requirement. The cost depends on the activated carbon used. Based on these numbers an average cost of **0.37 € per m³ PFAS-contaminated water** (for both long- and short-chain PFAS) is assumed.

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Table 16: Comparison of disposal techniques for PFAS-contaminated (fire run off and cleaning) for PFAS-based AFFF in HWI (hazardous waste incinerators and cement kilns)

	GAC	IX	PerfluorAd	Foam fractionation and Ozofractionation	Incineration
Background	The treatment of PFAS-contaminated water (or PFAS-containing AFFF) with activated carbon is based on the adsorption of a molecule on the surface of the activated carbon. This is facilitated by van-der-Waals interactions between the activated carbon and the target molecule. As these interactions can occur between any two molecules a broad variety of compounds may be adsorbed including some PFAS.	According to ITRC, IX is an effective sorbent for other contaminants and has historically been used for a variety of water treatment applications (for example, nitrate perchlorate arsenic). To date IX for PFAS removal from water is limited to ex situ applications.	PerfluorAd changes the solution equilibrium of PFAS in water. The reaction modes are precipitation and flocculation, mainly based on ion ionic interaction.	The process selectively separates PFAS from water by injecting compressed air (foam fractionation) or ozone (ozone fractionation) into the water in the form of air bubbles. PFAS surfactants adhere to the bubble walls and are thus transported to the surface. The PFAS-enriched foam is collected at the water surface for further destruction-based treatment. The treated water typically goes through a polishing step (e.g. GAC)	Literature indicates that hazardous waste incinerators at temperatures of 1 100 °C are able to destroy PFAS at more than 99%.
Technical performance	GAC removal capacity for PFOS is greater than for PFOA but both can be effectively removed. In general, shorter chain PFAS have lower GAC loading capacities and faster breakthrough times but could be effectively treated if changeout frequency is increased. There are currently no published studies on the effectiveness of GAC in removing cationic zwitterionic and anionic precursor compounds.	Various anion exchangers have been identified with a higher adsorption capacity towards PFAS than activated carbons. Similar to the adsorption onto activated carbon, the affinity of per- and polyfluoroalkyl sulfonates (PFSA) to ion exchangers is higher than those of per- and polyfluoroalkyl carboxylates (PFCA), and long-chain PFAS are sorbed preferably compared to short-chain PFAS.	The removal efficiency of PerfluorAd is depending on the chain length and the polarity of the PFAS. The long-chain sulfonic acids (PFSAs) show the best removal efficacy. PerfluorAd is used as the first PFAS treatment step within a treatment train (followed by GAC and/or IX).	No selectivity for PFAS-sub species reported. The process is not only suitable for the treatment of water, but also for sludge with a solids content of up to 20 %. Also ozonofractionation is used as the first PFAS treatment step within a treatment train (followed by GAC and/or IX).	According to current knowledge high temperature incineration in HWIs is an adequate technique to dispose, as PFAS are completely mineralised.
Remaining PFAS concentration	Proposed EU drinking water threshold of 0.1 µg/L for individual PFAS components (0.5 µg/L for total PFAS) are achievable by activated carbon treatment, but may require the use of several beds in series	Proposed EU drinking water threshold of 0.1 µg/L for individual PFAS components (0.5 µg/L for total PFAS) are achievable using ion exchange resins.	Designed for highly contaminated water with PFAS concentrations greater 0.3 µg/L. PerfluorAd is used as the first treatment step within a treatment train. Thus, this process is not intended to achieve final target threshold	For PFAS concentration levels below 0.3 µg/L high elimination down to a few ng/L could still be achieved	Remaining PFAS levels in bottom ash are very low. PFAS levels in exhaust air are unknown.

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	GAC	IX	PerfluorAd	Foam fractionation and Ozofractionation	Incineration
Side products & Emissions	Non-destructive technique, thus no side products. Emission may arise when the GAC is reactivated or incinerated. If reactivation is performed under 850 °C, formation of small chain PFAS compounds and fluorinated gases is possible.	Non-destructive technique, thus no side products. In single-use applications, the IEX resins are loaded with the PFAS and must be disposed for final destruction using high temperature incineration in HWI. Reactivation leads to PFAS-contaminated liquid waste (e.g. ethanol) that also needs to be incinerated.	values (e. g. 0.1 µg/L) as it is recognised that a further polishing step is required. Non-destructive technique, thus no side products. Emission may arise when the PFAS-PerfluorAd-sludge is incinerated.	Non-destructive technique, thus no side products. Emission may arise when the PFAS-foam is incinerated.	There are uncertainties concerning the emission of fluorinated substances, that could be produced when PFAS-based foams are incinerated. However, there is also no official standard to measure fluorinated substances in exhaust air. Currently a standard for the measurement of fluorinated substances in exhaust air is getting drafted.
Availability	Currently, GAC is a widely used water treatment technology for the removal of PFOS and PFOA, and, to a lesser extent, other PFAAs from water.	Accordingly, only limited experience in the EU is available from remediation on a technical scale. Due to the growing experience with this process, especially in Australia, it can be expected that ion exchangers will be used more frequently in the future.	The active ingredient is produced in the EU and according and there are no limitations regarding its availability. However, the active ingredient is not the only limitation criteria. This is more related to the manpower and material (including for example the activated carbon).	Only data from Australia and one case study from the UK are available.	The availability of HWI in Europe is different for each member state. Some countries do not have HWI and therefore need to transport their PFAS-based AFFF waste across borders.
Costs	Material cost: 0,41 – 3,68 €/kg	Material cost: 12 €/kg Treatment costs for long-chain PFAS of 0.05 to 0.1 € per m ³ and for short-chain PFAS of 0.25 to 0.8 € per m ³ respectively.	Material cost: 10-25 €/kg. For the entire PerfluorAd®/activated carbon system, operating costs (depending on the activated carbon used) amounted to < 0.055 – 0.68 € per m ³ of treated water, of which approx. 0.04 €/m ³ is attributable to the PerfluorAd® requirement.	Ozofractionation is a relatively complex technology whose operating costs are significantly higher than those of alternative market-ready technologies (e.g. GAC), but this cannot be assessed due to lacking data.	The cost for the disposal of 1 litre of PFAS-based AFFF are currently in the range of 0.2-2 €/l.

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E.4.2. Human health and environmental impacts

The human health and environmental impacts have already been considered and discussed alongside economic impacts above in the sections for each main effect of the possible restriction. A summary of the health and environmental impacts identified in each of these sections is provided in the table in Section E.9.2.

E.5. Risk reduction capacity

Both scenarios will eventually lead to an elimination of the use and therefore the emissions of PFAS-containing fire-fighting foams. Therefore, they can both be considered effective in addressing the identified concern and eliminating any further human health and environmental impacts of PFAS exposure related to the use of fire-fighting foams (noting that impacts of exposure related to legacy emissions may continue for a long time, considering the persistence of PFAS). The reduction of emissions would be achieved more quickly in RMO 2 and therefore RMO 2 would also achieve a higher reduction of cumulative PFAS contamination.

The evolution of PFAS emissions reduction under the two scenarios with different transitional periods has been modelled in Excel sheet below, which includes graphical representations.

https://activity.echa.europa.eu/sites/act-3/process-3-5/01%20Dossier%20preparation/36%20PFAS%20-%20Firefighting%20foams/03.%20Project%20management/Additional_consultancy_work/S_C3_emissions_and_costs_over_time/Calc_emission_20210311.xlsx

Summary text to be added.

Restriction option 2 (ban on the placing on the market and use) would lead to a rapid reduction of the currently estimated 117 tonnes of emission of PFAS in the environment per year due to the use in firefighting foams.

Restriction option 1 (ban on the placing on the market but use continued to be allowed until expiry date of the stocks) would lead to a reduction of PFAS emissions from this initial level but at a much slower pace.

Restriction option 3 (ban on the manufacture, placing on the market and use) would lead to the same rapid reduction of emission of PFAS in the environment as in Restriction option 2 and would in addition avoid the continued emissions due to the formulation for export after the transitional period.

Specific transition periods are proposed per type of foam use and the sensitivity analysis depicts the emission reductions and costs associated with other transition periods.

Commented [MD77]: Figure to be updated.

Commented [MD78]: @ Does it make sense? Same as the file presented further above (emissions over time).

E.5.1. Cost-effectiveness

Following ECHA's approach to the "Evaluation of restriction reports and applications for authorisation for PBT and vPvB substances in SEAC"²²⁶, the cost per unit (e.g. kilogram) of emission reduced are presented in the following. It should be noted that both the socio-economic costs and the emission reduction of a potential restriction of PFAS in fire-fighting foams is associated with significant uncertainties and are presented in wide ranges or sometimes indicative orders of magnitude. Not all socio-economic impacts (costs or benefits) could be quantified and often their magnitude will depend on the specific design of the potential restriction (e.g. residual concentration limits). As a result, the cost effectiveness will be subject to the same uncertainties and can only be calculated as an indicative order of magnitude.

Total emission reduction

Some 14,000-20,000 tonnes of PFAS-based fire-fighting foams are used annually in the EU (the best estimate used in Section E.4. is some 18,000 tonnes) and the market analysis suggested these contain an average concentration of fluorosurfactants of around 2-3% (average of 2.5% used as best estimate below). The emission model developed in Section B.9. estimated that 26% of the two modelled example PFAS surfactants used in fire-fighting foams are released to the environment. A range was not calculated, so a 50% range around that central estimate is used below. These assumptions yield the following estimate of total annual tonnage of PFAS emissions reduced if the use of PFAS-based fire-fighting foams in the EU were to cease:

(Table E.17 Estimate of total PFAS emissions from fire-fighting foams)

	Tonnes of foams used per year	Concentration of PFAS surfactants in foams	Share of PFAS surfactants released into the environment	Tonnes of PFAS released
Low	14,000 t	2%	13%	36 t
Best	18,000 t	2.50%	26%	117 t
High	20,000 t	3%	39%	234 t

Sources: Annex A and Annex B (Section B.9.)

It should be noted that this cost-effectiveness analysis only considers the reduction of PFAS emissions. The increased emissions of alternatives resulting from a potential restriction is not considered here, but the relative hazards of the alternatives are discussed in other relevant sections of this report.

Total cost of emission reduction

The main quantified costs (and benefits) of a potential restriction are listed below. Note that this list is for illustrating the approximate cost-effectiveness, but should not be understood as a total summary of costs and benefits. It should be read in conjunction with the economic impact assessment above to put these costs and benefits in context with the appropriate

Commented [MD79]: To be checked.

²²⁶ https://echa.europa.eu/documents/10162/13580/evaluation_pbt_vpvb_substances_seac_en.pdf/af4a7207-f7ad-4ef3-ac68-685f70ab2db3

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caveats and other unquantified impacts. In particular, benefits from avoided remediation costs have not been included here, because they constitute an environmental benefit rather than a cost of emission reduction. If these were included, they would significantly reduce the total costs (or even result in a net benefit)²²⁷. However, they remain an important benefit included in the SEA.

In order to compare the costs with annual emission reductions, one-off costs need to be annualised. Annualisation requires the selection of a cumulative time period over which to assess the cost-effectiveness of the restriction. Following ECHA guidance on SEA for restrictions²²⁸, this should reflect a typical investment cycle. The typical shelf-life of fire-fighting foams of 15 years (as assumed elsewhere in this report) has been used here, although it should be noted that related equipment may have much longer investment cycles and so a longer period could be used which would reduce the annualised cost. A 4% discount rate has been applied²²⁹. The total of annual costs plus annualised one-off costs shows that (at least at the chosen cumulative time period, for the costs and benefits that could be quantified) the one-off costs clearly dominate the balance of overall costs and benefits.

Table E.18 Estimate of total quantifiable cost of a potential restriction on PFAS in fire-fighting foams

Cost	Low estimate	Best estimate	High estimate	Notes
One-off costs				
Disposal of stocks (only RMO 2)	€210 million	€320 million	€435 million	Range based on central estimate cost per litre and likely range of tonnage to be disposed of. When considering full range of possible cost per litre, the range of total disposal costs could be €60m - €4.8bn.
Cleaning of equipment	€100 million (hypothetical 10% of best estimate)	€1 billion	€1.5 billion (hypothetical 150% of best estimate)	Best estimate based on the only cleaning process (and associated concentration of <1000ppt remaining PFAS achieved) for which a cost was available. Note that costs could be higher in RMO 2 than RMO 1, due to the shorter time available for cleaning, but no specific data was

Commented [MD80]: Kalle will look at this and try to reduce the ranges.

@Kalle: Please see also the paragraph "Costs from technical changes" above where I added a few elements that you probably need to take into account in the overall cost calculation. Note that this mostly apply to the oil/chemical sector. See also PFHxA comments #2893 and 3146.

²²⁷ Avoided remediation cost would be considered a one-off benefit, due to the long timescales of accumulated releases that lead to remediation. They could amount to in the range of hundreds of millions to billions of Euros. Annualised over 15 years, using a 4% discount rate, this would be equal to tens to hundreds of millions of Euros per year (annualisation method is described in more detail below).

²²⁸ https://echa.europa.eu/documents/10162/23036412/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

²²⁹ The discount rate has been chosen as per the example in the ECHA guidance and as recommended by the European Commission's Better Regulation Guidelines. In accordance with ECHA guidance on SEA for restrictions, the annualised costs is calculated as the annualisation factor multiplied by the one-off costs. The annualisation factor is equal to $r(1+r)^n / ((1+r)^n - 1)$, where r is the discount rate and n the cumulative time period.

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Cost	Low estimate	Best estimate	High estimate	Notes
Replacement of foam stocks (only RMO 2)	€320 million	€1.0 billion	€2.0 billion	available to quantify this. Range based on central estimate prices per tonne of PFAS-based foam and alternatives, and likely range of tonnage of alternatives to be purchased. When considering full range of possible prices per tonne, the range of total replacement cost could be - €60m - €8.3bn.
Total one-off costs	€100 million (RMO 1)	€1 billion (RMO 1)	€1.5 billion (RMO 1)	As per the notes above, the possible range could be even wider (low estimates €530m lower, high estimates €10.7bn higher).
	€630 million (RMO 2)	€2.3 billion (RMO 2)	€3.9 billion (RMO 2)	As per the notes above, the possible range could be even wider (low estimates €48m lower, high estimates €960m higher).
Annualised total one-off costs	€9.0 million (RMO 1)	€90 million (RMO 1)	€130 million (RMO 1)	
	€57 million (RMO 2)	€210 million (RMO 2)	€350 million (RMO 2)	
Annual costs				
Additional volumes of alternative foams	€21 million (RMO 1)	€27 million (RMO 1)	€30 million (RMO 1)	Under RMO 2, all PFAS foam stocks are replaced with new alternative foams at the beginning of the assessment period (already covered under the one-off cost replacement of foam stocks" above). These new foams would not expire within the assessment period, but an unknown share would be used and still need to be replaced again with new foams, thus incurring the costs associated with additional volumes again. Therefore, this cost is lower under RMO 2 but it cannot be quantified by exactly how much.
	€ several millions (RMO 2)	€10 million (RMO 2) (assumed mid-point between low and high estimate)	€20 million (RMO 2) (assumed value <€30 million)	
Disposal of expired foams	-€ several millions	-€1 million (assumed mid-point between low and high estimate)	-€100,000	
Clean-up	-€10s of millions	-€10 million (assumed mid-point between low and high estimate)	-€1 million (assumed value close to €0)	High estimate based on the assumption that at least in some cases, savings from reduced clean-up will be incurred, so total savings will be somewhat larger than €0.
Treatment of fire-water run-	-€10s of millions	-€ several millions	€0	

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Cost	Low estimate	Best estimate	High estimate	Notes
off per incident (annual unknown)		(assumed mid-point between low and high estimate)		
Total annual costs	-€ 10s of millions (i.e. a benefit)	€ several millions (RMO 1) -€ several millions (i.e. a benefit) (RMO 2)	€29 million (RMO 1) €19 million (RMO 2)	
Total annual costs + annualised one-off costs	-€ 10s of millions (RMO 1) ~€0 (RMO 2)	~€100 million (RMO 1) ~€200 million (RMO 2)	€160 million (RMO 1) €370 million (RMO 2)	As per the notes above, the possible range could be even wider (low estimates €48m lower, high estimates €960m higher).

Results rounded to two significant figures.

As a way of comparison, the Firefighting Foam Coalition indicated in their comment to the PFHxA restriction proposal that taking into account the loss of foam sales and the cost for procurement and disposal of foam agent and equipment, they estimate that the restriction as proposed would cost EU foam manufacturers and users more than 200 million€²³⁰.

Cost effectiveness

Based on the above, as a central estimate, it is calculated that the cost effectiveness could be around €850 (RMO 1) to €1,700 (RMO 2) per kg of annual reduction of PFAS emissions. This could range from savings in the tens of Euros per kg to costs around €10,000 per kg.

Table E.19 Estimate of cost-effectiveness of the reduction of PFAS emissions from fire-fighting foams

	Low estimate	Best estimate	High estimate
Total emission reduction (kg)	234,000 kg	117,000 kg	36,000 kg
Total cost (€)	-€ 10s of millions (RMO 1) ~€0 (RMO 2)	€100 million (RMO 1) €200 million (RMO 2)	€160 million (RMO 1) €370 million (RMO 2)
Cost-effectiveness	-€ 10s /kg (RMO 1) €0/kg (RMO 2)	€850/kg (RMO 1) ~€1,700/kg (RMO 2)	€4,600/kg (RMO 1) €10,000/kg (RMO 2)

Results rounded to two significant figures and reflect the likely range. However, as noted in the previous table, the range could possibly be even wider, from -€ 10s /kg (both Scenarios) to €31,000/kg (RMO 1) and €37,000/kg (RMO 2).

²³⁰ Comment 3010 in Part 2 document available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/25419/term>

E.6. Other impacts, practicability and monitorability

E.6.1. Social impacts

No significant social impacts have been identified. As discussed in Section E.4 “i. Other impacts”, there is potential for employment impacts but significant impact is deemed unlikely and any net effect at the EU level would be negligible.

E.6.2. Wider economic impacts

No significant social impacts have been identified. As discussed in Section E.4 “i. Other impacts”, under RMO 2, a potential shortfall in supply – driven by a one off need for stock replacement – may impact imports of fluorine free foam from outside the EU. However, overall, there are unlikely to be any significant macroeconomic impacts from the result of either RMO 1 or RMO 2.

E.6.3. Distributional impacts

No significant distributional impacts have been identified.

E.7. Practicality and monitorability

See Section 2.6.

E.8. Proportionality (comparison of options)

This section provides additional information to support the conclusions drawn in Section 2.7.

E.8.1 Detailed table supporting the comparison of the different uses

The table below summarises and compares substitution potential, socio-economic impacts and PFAS risk reduction potential across the main identified user sectors. Testing and training (across all sectors) are included separately because they vary significantly from application in actual fire incidents. The rows for user sectors refer to the use in actual fire incidents. Value judgements (“low”, “high” etc.) are relative, based on a comparison between the different sectors and applications. A higher substitution potential, lower socio-economic impacts and a higher PFAS risk reduction potential would suggest that stricter conditions can be imposed on the use/application in question, and vice versa.

Use / application	Substitution potential	Potential socio-economic impacts	PFAS risk reduction potential
Chemical / petrochemical	Low for some applications, medium/high for others: Sector includes many different and complex scenarios. Alternatives have successfully been implemented for some applications but may not be readily available for others. In particular, additional testing required to confirm feasibility of alternatives for large atmospheric storage tanks.	High: By far the largest user (59% of annual sales), so transition is large scale. Highest potential fire-safety risks from using alternatives, although relatively low risk of danger to human life.	High: By far the largest user (59% of annual sales), average potential for retention of run-off and clean-up after incidents.

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Use / application	Substitution potential	Potential socio-economic impacts	PFAS risk reduction potential
Marine Applications	High: Feasible alternatives considered to be available and have successfully been implemented by many users.	Medium: Average user (12% of annual sales), average potential for fire-safety risks from using alternatives.	Very high: Average user (12% of annual sales), likely lowest potential for retention of run-off and clean-up after incidents.
Military	Medium: Feasible alternatives considered to be available but not many have been certified or implemented by users yet.	Medium/High: Relatively small user (6% of annual sales), so relatively small scale of transition. Average potential for fire-safety risks from using alternatives, which could result in a relatively high potential of danger to human life.	Medium: Relatively small user (6% of annual sales), average potential for retention of run-off and clean-up after incidents.
Civil Aviation	High: Feasible alternatives considered to be available and have successfully been implemented by many users.	Medium/High: Relatively small user (9% of annual sales), so relatively small scale of transition. Average potential for fire-safety risks from using alternatives, but any risks would result in a relatively high potential of danger to human life.	Medium: Relatively small user (9% of annual sales), average potential for retention of run-off and clean-up after incidents.
Municipal Fire Services	High: Feasible alternatives considered to be available and have successfully been implemented by many users.	Low: Average user (12% of annual sales), so average scale of transition. Low potential for fire-safety risks from using alternatives.	High: Average user (12% of annual sales), likely lower potential for retention of run-off and clean-up after incidents because not restricted to specific industrial sites.
Ready to use applications	High: Feasible alternatives considered to be available. They have not yet been implemented by many users but ready to use applications rarely deal with large flammable liquid fires, so there is very little need for high performance foams.	Low/Medium: Relatively small user in terms of quantities (1% of annual sales according to Eurofeu data, several % based on estimated number of all fire-extinguishers) but potentially large number of devices affected (including millions of fire extinguishers). Very low potential for fire-safety risks from using alternatives.	Medium/High: Relatively small user, likely lower potential for retention of run-off and clean-up after incidents because not restricted to specific industrial sites.
Testing	Very high: Feasible alternatives considered to be available and have successfully been implemented by many users. No need for high performance foams.	Very low: Likely very small share of use, not the most expensive high performance foams required. Very low risk of damages resulting from performance of alternatives.	Low: Likely very small share of use, relatively high potential for retention.
Training	Very high: Feasible alternatives considered to be available and have successfully been implemented by many users. Little need for high performance foams.	Low: Likely very large share of use, but likely not the most expensive high performance foams required. Low risk of damages resulting from performance of alternatives.	Low/Medium: Likely very large share of use, but relatively high potential for retention.

Overall conclusions from this table are drawn in Section 2.7.1.

E.8.2 Stakeholder input on transition periods

Several users have provided input on manageable transition periods:

- One stakeholder claimed that a transition time of **10 years** would be needed for the switch in the **O&G / petrochemicals** sector. Another stakeholder from the same sector cited **5-10 years**, in order to minimise and spread the costs to change foam and re-build, or re-place fire extinguishing systems or equipment, but they would like to keep PFAS stocks in case of a big fire incident. As reported in the case study in Section E.2.4.2, Equinor took around 8 years to transition to fluorine-free foams.
- An industrial end user under consideration of discussions with some representatives from aviation industry groups and municipal users has developed a detailed draft proposed timeline covering a range of tasks required for a full transition to fluorine-free foams (across all sectors). The full timeline is provided in Annex 4, but key milestones suggested are (years from formal start of transition and introduction of legislation):
 - ▶ No more PFAS foam use in **training: Immediately**
 - ▶ No more PFAS foam use in **systems testing: 4 years**
 - ▶ No more PFAS foams used for **small incidents: 4 years**
 - ▶ **Completion of transition: 10 years.** The additional 6 years from the previous steps is largely driven by further replacement and disposal of stocks of legacy foam²³¹, as well as the need for further development of fluorine-free foams by manufacturers.
- A stakeholder from the **aerospace and defence** sector suggested the system change to enable use of non-PFAS foam could be introduced at time of major refit, which typically occurs every **6 -12 years**. On the other hand, the US Fiscal Year 2020 National Defense Authorization Act (NDAA) requires a phase-out of PFAS-containing firefighting foam in the US military (except on ships) by October 2024, i.e. within **4 years**.
- Several stakeholders across different sectors stated at the workshop or in response to the written consultation that **3-6 years** may be sufficient.
- One stakeholder suggested **different transition periods for different uses**. They explained municipal fire brigades should be able to transition quicker than operators of fixed installations for example. They argued that the use of fluorine free foam for tank fire fighting needs further testing and therefore more time.
- The PFHxA proposed restriction foresees the following transition periods: Concentrated fire-fighting foam mixtures placed on the market until 18 months after the entry into force of the restrictions can be used in the production of other firefighting foam mixtures until 5 years after the entry into force, except for use of fire-fighting foam for training and (if not 100% contained) testing. There is also an exception proposed for concentrated fire-fighting foam mixtures for certain defence applications until a successful transition to alternatives can be achieved, and for concentrated fire-fighting foam mixtures for cases of class B

²³¹ Note that this does not necessarily imply that no more PFAS based foams are purchased during that period.

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fires in storage tanks with a surface area above 500 m² until 12 years after the entry into force.²³²

Commented [MD81]: To be updated.

Conclusions from this input are drawn in Section 2.7.2.

E.8.3 Stakeholder input on concentration thresholds

The following thresholds were considered feasible by consulted stakeholders (all have been converted to ppb):

- Regulation in Queensland (Australia) allows up to **10,000 ppb** for PFOA/PFHxS and **50,000 ppb** for PFOA and PFOA related precursors and higher homologues. One stakeholder recommended these to be adopted in the EU as well.
- One stakeholder that has transitioned to fluorine-free foams (in the petrochemicals sector) reported that they had aimed for and achieved a level of 0.001% (**10,000 ppb**).
- One stakeholder reported experience with a relatively simple cleaning process (emptied tank, flushed two times with warm water) which can lead to very low remaining PFAS contamination (both when tested immediately and after a few years), but cautions a threshold below **100 ppb** would be unrealistic.
- Two stakeholders suggested **1 ppb** as the lowest achievable concentration in most cases. One of them linked this to a 32-stage legacy foam decontamination process costing €12,300 per appliance. In one-third of appliances this process can yield concentrations even lower (below 0.07 ppb).
- In terms of the lowest detectable concentrations, one stakeholder suggested laboratories are reported to be able to analyse down to a level of **30-150 ppb**. This is contradicted by other stakeholders that cite lower concentrations having been achieved and tested (see above). In the REACH restriction on PFOA, a concentration limit of **25 ppb** of PFOA including its salts or **1,000 ppb** of one or a combination of PFOA-related substances was adopted, based on the capabilities of analytical methods according to the RAC's opinion on the restriction dossier.

Conclusions from this input are drawn in Section 2.7.3.

E.9.1. Comparison of Restriction Options

See Section 2.7.

E.9.2. Comparison of costs and benefits

A brief summary of the main impacts (including costs and benefits), based on Section E.4.1. is provided in the table below. Insofar as costs and benefits could be quantified, they are also compared in the calculation of cost effectiveness in Section E.5.1.

²³² Note that these transition periods and exemptions may change when (and if) the proposal is taken forward.

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Table E.1 Summary of socio-economic considerations for the main expected impacts of potential regulatory management options

Commented [MD82]: To be updated.

Impacts	Economic	Social	Health/Environmental	Wider economic implications
a. Cleaning of equipment	Costs vary by equipment, process and achievable concentration. According to one estimate up to €12,300 per appliance achieving PFAS levels below 1000ppt (1/3 of appliances below 70ppt), which could imply EU total costs in the order of €1 billion, but established simpler methods have also been reported (cost not quantified). The replacement of equipment is likely to be required in some cases, depending on the threshold chosen. Replacement costs for extinguishers alone estimated at €15-450 mill on (EU total). Replacement cost for other equipment not quantified.	None identified.	Trade-off between cost for cleaning/replacement and threshold concentrations for remaining PFAS contamination. Replaced equipment and media (e.g. water) used in cleaning process must be disposed of or treated safely to avoid worker or environmental exposure.	None identified.
b. Other risk management options	None identified.	None identified.	None identified.	None identified.
c. Fire safety –impacts of technical performance of alternatives	It is not expected that any damages would be caused, see Health/Environmental. This is however still uncertain for large atmospheric storage tanks.	None identified.	AoA concluded alternatives are technically feasible and successful transitions have been shown in most applications. Further testing required to confirm whether this covers also large atmospheric storage tanks (LAST), the application of most concern.	None identified.

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Impacts	Economic	Social	Health/Environmental	Wider economic implications
			Speed of fire suppression may be slower and application of foams may be less flexible and less easy to use, according to some stakeholders. This has not been shown to be generally the case and resulting health/safety impacts could not be quantified.	
d. Use patterns to achieve comparable/acceptable performance using alternatives	Between no change in volume and up to a maximum of 100% additional foam required (additional cost considered in e. below). In sprinkler applications, special sprinkler nozzles have to be installed (cost not quantified). More than one foam may need to be stocked by users to cover different flammable liquids, with logistical, training and safety implications for users.	None identified.	More than one foam may need to be stocked by users to cover different flammable liquids, with logistical, training and safety implications for users.	None identified.
e. Economic feasibility of alternatives	<u>For both Scenarios:</u>	None identified.	None identified.	None identified.

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Impacts	Economic	Social	Health/Environmental	Wider economic implications
	Most likely there is no significant price difference (per litre) between PFAS-based foams and alternatives, but up to 100% more volume may be required (central estimate 50%) to achieve desired performance. This would lead to costs around €27m per year (EU total, central estimate) Potential additional economic costs for transitioning may include testing costs (not quantified), storage costs, (not quantified) costs from technical changes to delivery systems (e.g. €5-€200 per nozzle or around €2,700 for a mobile foam unit, but generally conceived as manageable), and regulatory approvals (not quantified). Potential savings may include lower foam disposal costs at expiry date (likely order of magnitude €100,000 to several million) lower fire-water disposal costs (covered under g. Remediation and clean-up), avoided cross contamination of waste, reduced regulatory requirements and reduced PPE requirements (not quantified). <u>Additionally for RMO 2:</u> Costs for existing stock of PFAS-based foams (estimated 210,000-435,000 tonnes) will have to be written off (and new stocks			

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Impacts	Economic	Social	Health/Environmental	Wider economic implications
	purchased causing an additional cost (central estimate €1.0bn) over the baseline.			
f. Environmental/health – impacts of alternatives	None identified.	None identified.	Based on the assessed substances, non-fluorinated alternatives are of lower environmental concern, primarily due to greater biodegradation. A quantitative comparison of risk under each scenario was not possible with the available data.	None identified.
g. Remediation and clean-up	Potential risk of PFAS contamination could be eliminated, which could save up to around €100 million remediation costs per site. Depending on the extent of containment and immediate clean-up, the number of relevant sites is likely low, but overall savings could still be in the order of magnitude of €100s of millions to € billions. More information on the total number of sites and real-world implementation and effectiveness of best practices would be required to be more precise. Treatment of fire-water run-off and short-term clean-up largely driven by other contents of fire-water run-off and cost saving estimates are very uncertain. Run-off treatment savings could be €0.7 per litre (range ca €0-€11) or €0 to €10s of millions per incident, and clean-up cost savings up to €10s of millions in total.	None identified.	Potential trade-off between remediation cost and remaining PFAS contamination.	None identified.
h. Availability of alternatives	Range of alternatives and capacity to increase production likely available. No significant	None identified.	None expected in RMO 1. The risk of supply supply-shortages is higher in RMO 2 (depending on timescales of a restriction),	None identified.

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Impacts	Economic	Social	Health/Environmental	Wider economic implications
	supply shortages or additional costs expected in RMO 1. RMO 2 may result in a more sudden and potentially significantly larger demand for fluorine-free foams to replace existing stocks of PFAS-based foam. This heightens the risk of a shortfall in supply, - depending on the timescales of any restriction. As the largest single use, and with comparatively low current fluorine free sales volumes, the risks of supply constraints may be greater in the chemicals and petrochemical sectors.		which could potentially lead to additional fire-safety risks.	
i. Other impacts	None identified.	There is potential for employment impacts but significant impact is deemed unlikely and any net effect at the EU level would be negligible.	None identified.	Under RMO 2, a potential shortfall in supply – driven by a one off need for stock replacement – may impact imports of fluorine free foam from outside the EU.

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Impacts	Economic	Social	Health/Environmental	Wider economic implications
				Overall, there are unlikely to be any significant macroeconomic impacts from the result of either RMO 1 or RMO 2.
j. Emissions from disposal of legacy foams	None identified.	None identified.	High temperature incineration has been identified as main disposal method. There are potential hazards (emissions of hydrogen fluoride and PFAS), but further research is needed to identify and quantify the emissions produced from the incineration of PFAS.	None identified.
k. Technical feasibility / availability of disposal options	If the transition period is short, there is the demand for disposal facilities may outstrip supply, leading to potential additional costs and potential for emissions.	None identified.	Trade-off between temperature of incineration (with lower capacity and higher costs) and effectiveness of PFAS destruction. If the transition period is short, there is the demand for disposal facilities may outstrip supply, leading to potential additional costs and potential for emissions.	None identified.
l. Costs of disposal	Total EU costs estimated at up to €320 million (range up to €60m-€4.8bn) depending on the method used (with implications on effectiveness, see Health/Environmental) and the share of foams that would have reached expiry date without use. Additional transport, storage and labour costs may be incurred (not quantified).	None identified.	Trade-off between temperature of incineration (with lower capacity and higher costs) and effectiveness of PFAS destruction.	None identified.

Annex F: Assumptions, uncertainties and sensitivities

The above conclusions are subject to a range of assumptions and uncertainties. Assumptions have been made based on the results of other sections and are discussed in more detail within those sections. However, the assumptions and uncertainties that could most significantly affect the results are discussed briefly below:

- Environmental/health benefits of the reduction of PFAS emissions could not be quantified, primarily due to a lack of knowledge about the hazards of PFAS. The estimated emissions of PFAS and hazards of the constituents of alternatives are also subject to a range of uncertain assumptions. Hence, costs and benefits could not be directly compared;
- Cost of transition are subject to uncertain assumptions about price difference between foams and the quantity of alternative foams needed to achieve the desired performance. Which and how much alternative foam is needed to achieve the desired performance varies on a case by case basis. It has been judged most likely that there is no significant price difference (per litre) between PFAs-based foams and alternatives, and assumed that 50% additional volume of alternatives is needed. If a more/less expensive alternative foam or larger/smaller quantities would be needed to achieve the desired performance, this would increase/decrease the costs of the restriction. Savings related to the transition are sensitive to assumptions about the amounts of foam that would reach their expiry date without use under the baseline;
- Costs of cleaning and technical changes or replacement of equipment are very case-specific and could largely not be quantified with the available data. This means that the quantified costs of both scenarios are underestimates;
- It should be noted that there was a divergence in the stakeholder input about technical feasibility of alternatives. A few stakeholders have voiced concerns over the potentially reduced fire safety, at least in specific applications. This means there is a risk of additional health, safety and economic (fire damage) impacts; however our analysis has concluded that they are not the most likely outcome and that LAST are the main application for which there is still further testing required;

It is uncertain to what extent current practices involving the use of PFAS-based fire-fighting foams already manage to eliminate the need for significant new remediation requirements under the baseline. This is because most experiences with PFAS remediation relate to legacy contamination resulting from historical emissions before current measures (e.g. containment and clean-up after use) were widely implemented. However, stakeholder input suggests that such measures are likely not 100% implemented or effective. Furthermore the incremental costs of addressing PFAS contamination in short-term clean-up is difficult to separate from the wider clean-up costs involved after fire incidents. In addition, there is a lack of data about the number of sites that use PFAS-based foams in sufficient quantities to potentially require clean-up or large scale remediation. Therefore remediation savings from the transition to fluorine-free alternatives are very uncertain and only illustrative estimates of the potential order of magnitude of such benefits were provided; and

There is a wide range (€60-4,800 million, with best estimate €320 million) in the potential costs of disposal of legacy foams in RMO 2, which largely depends on the disposal method used. This is due to uncertainty about the amounts of foam that would reach their expiry date without use under the baseline and the effectiveness of PFAS-destruction at different

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incineration temperatures and times. There is also uncertainty about the potential emissions and therefore associated environmental/health risks.

Annex G: Stakeholder information

Introduction

At the beginning of this project it was recognised that effective engagement with key stakeholders from across the fire-fighting foam sector, particularly the manufacturers and users of the foams, would be critically important in the data collection process.

The stakeholders consultation cover all the relevant sectors and backgrounds across the fire-fighting foam supply chain, as well as regulators, researchers and special interest groups. The consultation therefore aimed to target the following stakeholders:

- Foam manufacturers / suppliers;
- Users of foams in major sectors (including airports, oil and gas, chemical plants, ports, railways);
- Key trade associations;
- International organisations;
- National-level authorities and agencies;
- Academics and R+D (especially those involved in developing alternative foam products); and
- Key NGOs and interest groups.

The consultants Wood, Ramboll and COWI mapped stakeholders identified so far, indicating the best means of consulting each one of them: e.g. advisory group, questionnaire, one-to-one consultation, workshop, etc. An initial list of stakeholders was provided by the consultants and a finalised list was agreed with the Commission and ECHA prior to commencing the consultation activities.

Approach

The agreed approach to collecting key information from the main categories of expert stakeholders (detailed above) was to carry out a consultation through a combination of i) scoping interviews, ii) a targeted stakeholder questionnaire, and iii) a stakeholder workshop. The approach to carrying out these consultation activities is outlined in the following sections.

Scoping interviews

To inform the main data collection steps of the project (the stakeholder questionnaire and workshop) a series of initial scoping interviews was organised with a selected small number of key stakeholders. The purpose of the interviews was to:

- I. Introduce and discuss the aims and scope of the project with key experts;
- II. Identify where the key data gaps were in relation to the objectives of the project(s); and
- III. Identify other key stakeholders in this sector to target in the next stages of the consultation.

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The stakeholders involved with the scoping interviews were:

- Eurofeu;
- Fire Fighting Foams Coalition;
- Copenhagen Airport;
- Heathrow Airport;
- LASTFIRE project; and
- IPEN.

An interview template was developed, and shared with the interviewees ahead of the call, to guide the conversation more effectively and efficiently. Teleconference interviews of 30-60 minutes were held with each stakeholder. During the call, brief notes of the key discussion points were made.

Since the purpose of these scoping interviews, was as an introductory discussion, rather than an evidence gathering exercise as such, a limited amount of specific information about the use of fire-fighting foam products was gained. A number of key outcomes from these scoping interviews are highlighted below:

- All stakeholders interviewed expressed an interest in the project and agreed to participate in the consultation;
- In some cases, for example, for key industry associations, it was agreed they would coordinate joint industry responses, and stakeholders provided the details of additional stakeholders to contact, and/or agreed to forward the consultation on directly;
- Both industry, users and others (e.g. NGOs) commented on the increased move towards and the rapidly increasing market share of fluorine-free foams, and their increasingly better overall performance now than previously;
- It was re-emphasised that alternative foams are designed for very specific applications, requiring compliance with specific performance criteria, so the analysis of their technical and economic feasibility will be challenging as it requires assessment of each product individually;
- There is likely to be variation in the situations with regards to alternative foams in different sectors of use (e.g. between aviation and oil and gas sectors) and in different locations/countries (e.g. certain countries have switched to alternatives, others have not); and
- The potential for contamination of foams was raised, leading to the inclusion of specific questions in the survey about the level of PFAS as impurities in foam products (both PFAS-based and fluorine-free).

The scoping interviews were then used to better inform our approach to the following consultation steps, allowing the survey and workshop to be designed more systematically to address the key knowledge gaps and target the most relevant stakeholders. This also helped to identify additional stakeholders to include in the next consultation steps.

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Consultation questionnaire

The main consultation activity conducted involved the development of a written questionnaire, based on an assessment of the required data needed to generate and/or complement the information already gathered under the separate Tasks under the two projects.

It was agreed that the most appropriate format of the questionnaire would be a Word document that could be sent to targeted stakeholders directly via email, allowing the respondents to fill in relevant details and return the completed questionnaires.

The questionnaire covered the following aspects:

- Introductory information;
- Background information on the respondent;
- Chemical identity, functionality of PFAS in fire-fighting foams;
- Alternatives to PFAS in fire-fighting foams;
- Foam use and environmental emissions;
- Potential restrictions on PFAS in fire-fighting foams; and
- Additional information.

The full consultation questionnaire is provided in Appendix 1 of the underlying study²³³.

Consultation questionnaire results

A total of 33 written responses to the questionnaire were received²³⁴.

Of the different types of stakeholder targeted, the most responses were from users/industry (11), with smaller numbers of responses from individual manufacturers (2), authorities/agencies (6), industry associations (2), NGOs (3) and 'other' stakeholders (7) e.g. academic/testing/training professionals/technical consultant. It is noted that the responses from the users of foams cover all the main sectors of use the consultation aimed to cover (airports, oil refineries/storage, chemicals, petrochemicals, and rail).

Responses to the consultation from a number of stakeholders also included the provision of previously published data or reports in addition to, or instead of, the questionnaire. This included published reports and analyses from national authorities²³⁵, research and testing information²³⁶, and special interest groups²³⁷.

²³³ Wood, Ramboll, COWI: "The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report". Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

²³⁴ Correct as of July 18 2019.

²³⁵ KEMI (2015) Chemical Analysis of Selected Fire-fighting Foams on the Swedish Market 2014

²³⁶ Published testing data, as provided by LASTFIRE: www.lastfire.co.uk/

²³⁷ IPEN (2019) The Global PFAS Problem: Fluorine-Free Alternatives as Solutions, <https://ipen.org/documents/global-pfas-problem-fluorine-free-alternatives-solutions>

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Since the questions in the stakeholder questionnaire were designed to gather information that will best feed into the delivery of tasks under each of the two projects, the responses received have generated useful information in this context. In particular, we highlight the following aspects, where the consultation yielded useful information:

- Identifying some of the key foam products containing PFAS on the EU market, and non-PFAS alternatives actually used in key sectors;
- Identifying specific PFAS, precursors and impurities present in some foam products;
- The functionality of PFAS-containing foams useful to the major users of foams and reasons why products containing PFAS have not been fully replaced;
- Volumes of production and use, and unit price for a small number of individual products;
- Information on available alternatives, including specific products on the market in the EU, the type and sector of use, their availability, volumes of sale and use, their perceived technical feasibility and economic feasibility;
- Some details of fire-fighting foam use e.g. volumes, frequency;
- Some details of methods, regulations, and guidelines in place to prevent release to the environment;
- Some information on the methods/approach to disposal of individual foam products;
- Preliminary stakeholder opinions and feedback on different potential restriction options were provided; and
- Additional data, reports and other resources were provided by a number of stakeholders with their consultation response.

For some sections, a number of information gaps, where the level of detail provided by respondents was less substantial, were identified. These data gaps helped to inform the approach to the organisation and format of the following stage of the consultation process, the stakeholder workshop, where these data gaps were explored further (see next section).

Consultation workshop

The final stage of the consultation involved the organisation of an expert stakeholder workshop. This was hosted by ECHA in Helsinki on 24 September 2019.

The purpose of the workshop was to present, validate and seek feedback on the preliminary project findings; gather views on possible risk management options; and explore the feasibility of replacing PFAS-based foams with fluorine-free alternatives. Stakeholder views were sought during the workshop through a series of breakout groups on key topics which focused on specific questions designed to inform possible future regulatory activities.

The workshop was attended by a total of 36 participants, including manufacturers, users from different sectors (airports, chemical plants, oil and gas), researchers, NGOs, national authorities, and remediation experts.

The format of the workshop included:

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- Introductions from DG Environment, ECHA and the study team;
- Presentation of initial results;
- Plenary discussion on study findings to date;
- Presentations from invited speakers; and
- Breakout session on remaining data gaps.

The invited speakers, who presented at the workshop were from the following organisations:

- Eurofeu (industry perspective);
- Finavia Corporation (user perspective – airports);
- Total HSE (user perspective – oil and gas); and
- LASTFIRE project (testing and efficacy perspective).

There were four breakout sessions for the workshop, each covering a specific set of questions, partly informed by the identified data gaps remaining from the consultation questionnaire and the other tasks relating to the two projects. The breakout sessions covered the following aspects:

- Different Risk Management Options;
- Essential uses and availability of alternatives;
- Remediation costs and technologies; and
- Current/ future market trends in PFAS-based and fluorine-free foams.

The workshop report with more details about the set-up and results of the workshop is included in Appendix 2 of the underlying study²³⁸.

Additional consultation and resources

The stakeholder consultation and workshop also resulted in a number of stakeholders providing additional information to supplement their consultation responses. This additional information was used, where relevant, in each of the specific tasks.

Following the consultation questionnaire and workshop, a number of specific areas were identified as needing additional data or clarification, for example on volumes of firefighting foams produced, marketed and used in the EU. Where these additional data needs were identified, the project team undertook direct consultation with specific stakeholders identified as being the best source of the required information. Contact was made with these stakeholders via email or telephone to discuss the remaining data needs and obtain the

²³⁸ Wood, Ramboll, COWI: “The use of PFAS and fluorine-free alternatives in fire-fighting foams - Final report”. Report for the European Commission DG Environment and European Chemicals Agency (ECHA) under specific contracts No 07.0203/2018/791749/ENV.B.2 and ECHA/2018/561.

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required data. This additional consultation has provided additional detail and clarifications relating to critical uses, volume of production and use in the EU, and experiences from previous transitions.

Annex H: Stakeholders survey on techniques to clean equipment

4.11. Cleaning procedure by BIOEX

According to their homepage²³⁹, BIOEX launched 2002 the first Fluorine-Free Foam on the market: ECOPOL. The BIOEX customer support services provide customer assistance in case of urgent need of foam concentrate, foam sample analysis and testing. BIOEX provides a foam calculation tool defining foam concentrate needs. BIOEX also supports companies in their transition to Fluorine-Free Foam (F3).

4.11.1. Background

According to the BIOEX homepage, BIOEX F3 foams are compatible with existing proportioning equipment. We must define appropriate foam application rate and discharge duration. It may induce minor system modifications.

4.11.2. Cleaning Procedure

PFAS cleanout with replacement costs and time. BIOEX recommends the following cleanout protocol, in case downstream users don't want to replace pump and storage tank:

1. Drain all foam from tank
2. Flush tank and pipes with hot water and scrub where possible
3. Rinse water analysis at lab to confirm PFAS cleanout
4. F3 Foam replacement: tank refilling with F3
5. Test/commissioning with the concentrate: the finished foam quality is highly dependent on the hardware (foam proportioning system, distribution system and discharge device)
6. Fluorinated foam disposal

Based on this protocol and the fact that the disposal of the cleaning water is not discussed, it can be assumed that water stemming from the cleaning itself are not disposed as hazardous waste.

4.11.3. Remaining PFAS concentrations

There is no information available on remaining PFAS concentrations.

4.11.4. Costs

There is no information available on costs for this technique.

4.11.5. Additional information and available case studies

There is no information available on available case studies.

Commented [MD83]: @Daniele: could you please adjust the formatting of this section? E.g. "Cleaning procedure by BioEX" should be point 1, "Background": 1.1, etc. Thanks.

²³⁹ See [here](#), last accessed at 05th February 2021

4.12. V171 by Arcadis

4.12.1. Background

According to the JOIFF-article (which has been authored by Ian Ross and [REDACTED] Storch from Arcadis), decontamination of firefighting and fire suppression equipment is essential to limit carryover of PFASs from old foam usage. Triple rinse with water is not sufficient and leads to a significant volume of decontamination water that requires treatment. Arcadis recommends using specialized biodegradable cleaning agents such as V171 to effectively remove PFAS residuals from fire suppression systems to limit future liabilities and cost associated with PFAS contaminating F3 foams as a result of inadequate decontamination (JOIFFF 2020).

Arcadis has developed methods for PFAS decontamination of piping and tank systems including the use of a proprietary biodegradable cleaning agent, V171. These methods and the cleaning agent have been successfully applied in foam transition projects to remove PFASs from steel and PVC piping systems, stainless-steel concentrate tanks, and underground wastewater tanks (JOIFFF 2020). Also application in foam suppression systems, emergency response vehicles, and concrete sewer distribution systems are described (Anderson 2021).

In chapter 5.5, the technical performance and other details of this technique has been described. The following information concentrate on the actual cleaning procedure.

4.12.2. Cleaning Procedure

The initial PFAS cleanout project in 2017 used a sequential series of aqueous rinses, high- pH flushes and application of the cleaning agent as shown in Figure 17. presenting Sum of PFAS (28) TOP Assay results. The results demonstrated that water and high pH are ineffective for removal of PFASs from surfaces, as demonstrated by the relatively low concentrations of PFASs measured in these flush solutions. The elevated concentration in the cleaning agent demonstrated significantly greater PFAS mass removal even after multiple flushes of water and caustic solution.

Further work to clean PFASs out of a 20- m³ foam concentrate tank was conducted, and results are presented in Figure 17. This application demonstrated that soaking with the cleaning agent, followed by high-pressure washing can be effective. The importance of using TOP assay for analysis of PFASs was revealed.

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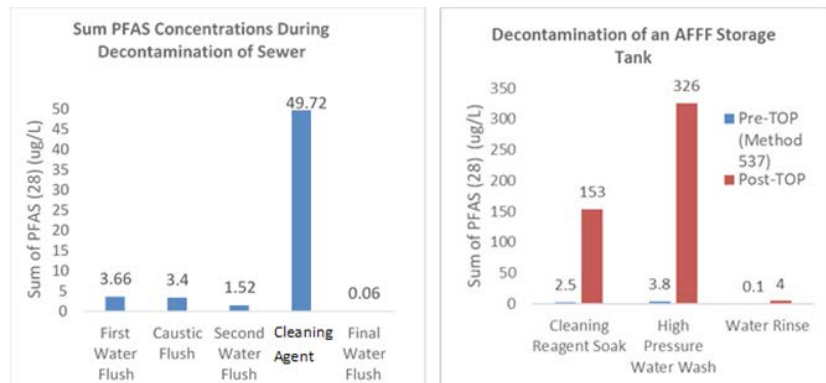


Figure 19: Sum of PFAS Concentrations during decontamination of AFFF- Impacted sewer system and of a 20-m³ concentrate tank

4.12.3. Remaining PFAS concentrations

As shown above in the diagrams of Figure 17, the final water flush/rinse contained around 0.1 µg/l PFAS as measured for the sum of 28 PFAS (according to TOP 4 µg/l).

4.12.4. Costs

There is no information available on costs for this technique.

4.12.5. Additional information and available case studies

Available case studies has been already discussed in chapter 5.5 under “Additional information and available case studies”.

In addition, Arcadis claims that the technique has been successfully applied in foam transition projects to remove PFASs from steel and PVC piping systems, stainless-steel concentrate tanks, and underground wastewater tanks (JOIFFF 2020). Also application in foam suppression systems, emergency response vehicles, and concrete sewer distribution systems are described (Anderson 2021). For these projects, no documentation has been found via desktop search.

One ongoing study for the DoD focuses on Fire Suppression Systems.

- US-Department of Defence (DoD) concerning the “Demonstration and Validation of Environmentally Sustainable Methods to Effectively Remove PFAS from Fire Suppression Systems”.

4.13. Cleaning procedure with PerfluorAd by [REDACTED]

4.13.1. Background

Detailed information on the background of this technique has been already given in chapter 5.2.

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Cleaning Procedure

Cleaning of PFAS Contaminated Fire Fighting Trucks and Equipment as well as Stationary Fire Extinguishing Systems in the Transition Process from AFFF Foams to Fluorine-free Foams with Cornelsen's PerfluorAd Technology is executed in 3 Steps (Cornelsen 2021):

1. Complete and careful emptying of all System Components (possibly even with partial replacement of Components): Pipes, Hose Lines, Seals, Valves, Pumps, Fittings, Tanks including Partitions and hidden Areas, ...
2. Performing a Flushing of all individual Pipelines with a PerfluorAd Dilution. The last Flushing is carried out with Fresh Water. The visually recognizable Foam Formation serves as an Indicator for the Degree of Cleaning.
3. Treatment of the collected Rinse Water directly on site with a further PerfluorAd application. Off-site Disposal of Rinse Water does not take Place. The PFAS Content of the Rinse Water can already be significantly reduced when using the PerfluorAd Technology exclusively.

The steps are identical for the cleaning of equipment of fire brigades and for stationary fire extinguishing systems. In Figure 18 the three individual steps of the cleaning procedure are shown schematically. The cleaning of stationary equipment is shown at the left and the cleaning of fire brigade machines is shown at the right (no illustration available for the first step).

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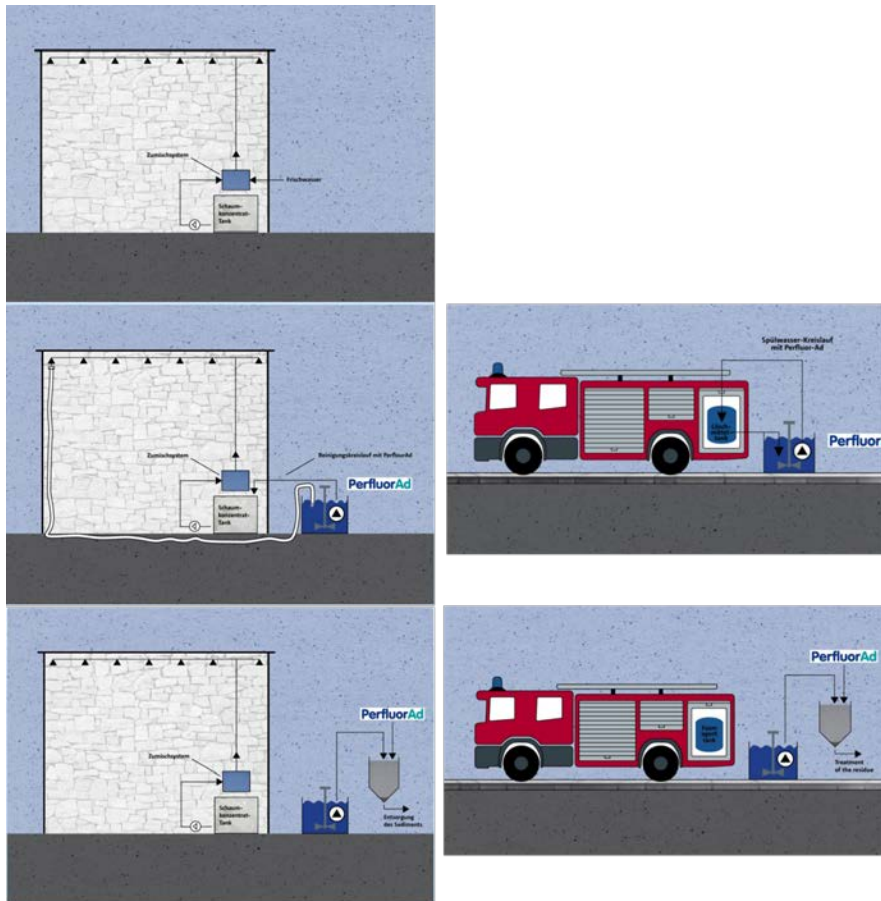


Figure 20: Schematic overview on the three individual steps of the cleaning procedure are shown schematically. The cleaning of stationary equipment is shown at the left and the cleaning of fire brigade machines is shown at the right (no illustration available for the first step)

4.13.2. Remaining PFAS concentrations

According to [REDACTED] the achievable PFAS residual concentrations in the system depend on several factors:

- Degree of emptying of the entire system (do PFAS deposits still remain in the system after emptying has been completed?)
- Materials present in the system (plastic, GFK, rubber, ...)
- Are all components accessible for mechanical cleaning (steam jet, brush, ...) or can adhesions remain in places that cannot be seen?
- What is the effort involved in replacing "critical components" (e.g. are all seals and plastic parts replaced before cleaning?)
- If complete emptying is possible and subsequent "bleeding" of PFAS from individual components is impossible, and at least 3 (better 5) rinses with a PerfluorAd dilution

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and a final rinse with fresh water are performed (Depending on the boundary conditions described before, flushing water volumes of >15 to <30 m³/vehicle are often required in practice),

Considering all of these factors, using the PerfluorAd technology final residual concentration (measured in the final rinse with fresh water) of less than 1.0 µg/l total PFAS, very often less than 0.3 µg/l to 0.0 µg/l can be achieved.

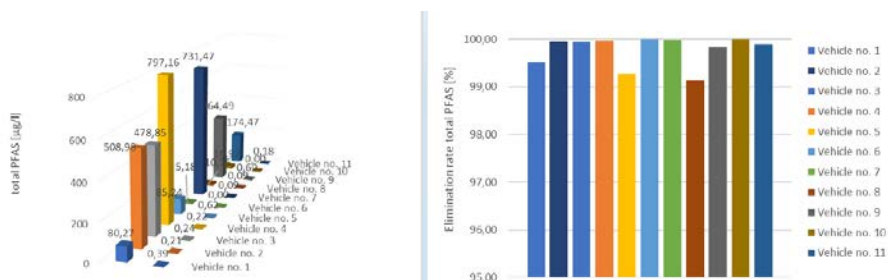


Figure 21: Results of the Cleaning of Fire Trucks using PerfluorAd

4.13.3. Costs

According to [REDACTED] several parameters flow into the pricing, such as size, type, age ... of the vehicle, disposal of the AFFF concentrate to our extent (Y/N?), place of cleaning (in our approved installation in Essen or at the customer's?), etc. Depending on these boundary conditions, the costs are usually between 20,000-25,000 Euro/vehicle. These figures include the treatment of all rinsing water and all disposal costs [REDACTED] Interview 2021).

4.13.4. Additional information and available case studies

- A typical PerfluorAd application is the cleaning of fire brigade trucks. For this [REDACTED] GmbH is accredited by a German environmental authority. The process takes approx. one working week (Monday to Friday). However, a longer time is needed if components need to be replaced. [REDACTED] GmbH is providing the plant and needed personnel. According to MC, several parameters flow into the pricing, such as size, type, age ... of the vehicle, disposal of the AFFF concentrate to our extent (Y/N?), place of cleaning (in our approved installation in Essen or at the customer's?), etc. Depending on these boundary conditions, the costs are usually between 20,000-25,000 Euro/vehicle. These figures include the treatment of all rinsing water and all disposal costs.
- In the last 6-12 months [REDACTED] GmbH is receiving more inquiries from companies with large fire extinguishing systems. MC mentioned that the costs for systems are very hard to extrapolate, as they differ based on the needs of the company. In large fire extinguishing systems, the PFAS-concentrates normally are contained in the tank, tank to mixer pipes, and finally the mixer. Based on the knowledge of MC, PFAS-contamination is not to be expected after the mixer. However, if there have been incidents/training with PFAS-foams then also these systems are expected to be contaminated. In MC's understanding, cleaning of all systems is not required, thus, only PFAS-containing systems (as described before) would need to be cleaned. Based on MC's opinion, a replacement of critical components (plastics, etc.) is advisable to remove PFAS-substances and to prevent future "bleeding" of PFAS-substances.

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- The state of North Rhine-Westphalia has funded the production of a mobile extinguishing water treatment plant (MLB) using the PerfluorAd process. This plant will be made available to the market in July 2019 and will be kept by [REDACTED] Umwelttechnologie GmbH at the company's site in Essen and, if required, "mobilized" at short notice, i.e. transported to the site of the fire, so that the collected PFC-contaminated firefighting water can be purified directly on site. With the approval of the responsible authority, the cleaned water is discharged into the sewer system. Alternatively, the MLB can also be used directly at sites with the consent of the responsible authority. authorities, the MLB can also be used directly at locations where collected extinguishing water is temporarily buffered, e.g. at waste disposal companies, sewage treatment plants, etc. The operation of the MLB and the cleaning process of the collected extinguishing waters are carried out by [REDACTED] as services.

4.14. Cleaning protocol by the Bavarian State Ministry for the Environment and Consumer Protection (LfU)

4.14.1. Background

The Bavarian State Ministry of the Interior, Sports and Integration and the Bavarian State Ministry for the Environment and Consumer Protection in cooperation with state fire department schools, working group of professional fire departments, state fire department association, plant fire brigade association, Bavarian insurance chamber and VdS Loss Prevention GmbH published a document about the environmentally friendly use of firefighting foams in September 2019.

Topics are environmental relevance of foam extinguishing agents, distinguishing between fluorine-containing and fluorine-free foam extinguishing agents. Also, the evaluation of the environmental compatibility of foam agents. Furthermore, the basics of extinguishing foam, as well as procurement, use and disposal.

In the following it is focused on the cleaning instructions of equipment when replacing fluorine-containing with fluorine-free foam extinguishing agents. The main goal, as described in the guideline is to prevent contamination of fluorine-free foam concentrate with PFAS.

In general, the guideline recommends not to reuse used foam concentrate canisters and intermediate bulk containers (IBCs) that have contained fluorosurfactant foam concentrate. Furthermore, in the case of smaller tanks and IBCs, the guideline states that removing those might be more efficient compared to a time-consuming cleaning procedure. Permanently installed foam concentrate tanks in vehicles must be thoroughly cleaned before refilling with fluorosurfactant-free foam concentrate.

During the course of this project, [REDACTED] Michael Gierig from LfU has been interviewed and important information was collected.

Cleaning Procedure

Good cleaning results can be achieved with stainless steel tanks and tanks made of polyethylene or glass-fiber reinforced plastic (GRP), on condition that the tank cleaning is carried out very carefully.

In detail, the LfU-GL is recommending the following cleaning procedure for stainless steel tanks, GRP and polyethylene tanks:

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1. Complete draining of the foam concentrate (dispose of foam concentrate)
2. Remove foam concentrate residues mechanically and by rinsing with hot (50-60 °C) water. All pipes and fittings carrying foam concentrate must also be rinsed during this process. The rinsing process is sufficient when the draining water no longer foams. The flushing water must be disposed of²⁴⁰.
3. The tank, the lines and fittings carrying the foaming agent must be completely filled with water that is as hot as possible. The water must remain in the tank for at least 24 hours. After that, the water must be completely drained and disposed of.
4. The tank, the pipes carrying the foaming agent and the fittings must be completely filled with hot water three more times. The water must remain in the tank for at least 24 hours each time. The rinsing water from these rinsing processes can - if careful procedures are followed - be discharged via the sewage system into the sewage treatment plant.

After this cleaning procedure, the tank can be filled with fluorosurfactant-free foam concentrate. The complex cleaning process ensures that the new, fluorosurfactant-free foam concentrate is not contaminated with fluorosurfactants from the tank wall.

4.14.2. Remaining PFAS concentrations

According to stakeholder knowledge, the effectiveness of the cleaning is monitored by measurements. A foam concentrate tank can then be released for further use if sufficient cleaning success is guaranteed. As a rule, concentrations below 10 ng/l of each of the 13 standard PFAS²⁴¹ can be achieved with the cleaning procedure described in the guide and, if necessary, replacement of all accessible seals (LfU-Gierig-Interview 2021).

The stakeholder reported, that usually < 10 ng/l, i.e. 10 ppt, related to foam concentrate tanks in fire engines are achievable. LfU does not have any figures for stationary extinguishing systems. LfU also sometimes accepts cleaning efficiencies the range of 100 ng, when special circumstances are to be considered (PFAS-emitting gaskets cannot be replaced).

4.14.3. Costs

Costs are available for tank fire engines. Costs are approx.- 100.000-200.000 € per engine, when a permanently installed foam concentrate tank is cleaned before refilling with fluorosurfactant-free foam concentrate.

²⁴⁰ Referring to the Lfu-guideline foaming agents containing fluorine surfactants must be disposed of by suitable disposal companies (German waste code number usually 16 10 01* = aqueous liquid waste containing hazardous substances). Certified disposal companies can be researched at www.lfu.bayern.de/abfall/entsorgerfachbetriebe/recherche/index.htm.

²⁴¹ Measurements based on DIN 38414-14 the German standard methods for the examination of water, waste water and sludge - Sludge and sediments (group S) - Part 14: Determination of selected polyfluorinated compounds (PFC) in sludge, compost and soil - Method using high performance liquid chromatography and mass spectrometric detection

4.14.4. Additional information and available case studies

- According to stakeholder knowledge, the Munich Fire Department has cleaned its permanently installed foam concentrate tanks according to this guideline. Likewise, other fire departments in Bavaria are likely to have successfully cleaned their foam concentrate tanks according to this procedure (LfU-Gierig-Interview 2021).
- According to stakeholder knowledge, In Bavaria, there are approximately 1,000 fire engines with permanently installed foam concentrate tanks. Most of these tanks can be sufficiently cleaned with the recommended flushing procedure. The residual quantities are tolerable, especially since a large number of fire extinguisher fills containing PFAS are still in circulation. It would be completely uneconomical to completely replace the vehicle tanks as long as significantly higher inputs of PFAS are present in other areas (LfU-Gierig-Interview 2021).

4.15. Cleaning protocol by Fire Rescue Victoria (FRV) - Appliance PFAS Decontamination Project

Fire Rescue Victoria and the United Firefighters Union developed a decontaminate procedure for appliances (fire trucks). According to their own knowledge, FRV are the only firefighting authority in the world that has achieved this. Due to the verified success of this PFAS decontamination work, FRV have assisted many other emergency service agencies, to either advise or provide similar decontamination processes and applied safe threshold limits for their respective firefighting appliances. FRV are considered national leaders in the successful implementation of measurable PFAS mitigation work.

Background

The MFB previously used PFAS containing Aqueous film forming foams (AFFF) as firefighting foam, based on 3M's earlier recommendation of it being safe. Global use of PFAS containing AFFF firefighting foam is the source of approximately 30% of the world's PFAS contamination.

In 2007, MFB made a decision to replace existing firefighting foam with fluorine-free firefighting foam. This decision was on the basis of concerns relating to firefighter health and environmental issues. MFB then phased out the use of persistent PFAS-containing firefighting foams across its operations.

MFB engaged expert independent environmental consultants to analyse PFAS exposure pathways for MFB firefighters on the job. This report was used to inform and develop MFB PFAS threshold limits and prioritise PFAS mitigation work.

The MFB (FRV) developed and formally endorsed an 'Operational Use of Firefighting Foam Policy' and the use of fluorine free foam. Victorian Environmental Protection Authority (Vic EPA), and Victorian WorkSafe played a part to formalise this policy.

By 2014, all MFB firefighting appliances had been converted to only carry fluorine free B Class foam in their foam tanks. Following the MFB establishment of the safe PFAS thresholds, in 2016, MFB embarked on a process to test and decontaminate the MFB firefighting fleet. Further work is currently being done to PFAS decontaminate more recently introduced FRV appliances and monitoring the previous PFAS decontamination work on the earlier MFB appliances.

Cleaning Procedure

FRV used independent environmental consultants and our industrial cleaning partners, to develop a 32-stage decontamination and verification process targeted at ensuring that the

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appliances, after decontamination, can be safely returned to service. A detailed description of all steps is shown in the annex (see chapter 7.1). In the following each of the steps will be shortly introduced (information taken from a presentation submitted by a stakeholder (Fire-Rescue-Victoria 2021)):

1. Suitable Facility for the PFAS Decontamination process: Fire trucks are taken to a specially constructed decontamination facility, where the removable components (hoses, connectors, ladders etc.) are stripped off for separate decontamination. The trucks are then put into a bund system, where the raw foam is carefully pumped out and the tanks prepared to be flushed and cleaned.
2. Flushing of the tanks: The tanks are carefully flushed with slowly introduced, temperature controlled, water to maximise raw-product foam removal whilst minimising foam creation. Wastewater is collected for future processing and disposal. After removal of the majority of foam product, agitation is introduced to break down and dissolve solidified foam product. Separate, colour-coded pumps and pipelines-lines are maintained to ensure that cross-contamination is avoided. Filters, strainers and breathers are carefully dismantled to allow removal of solidified foam product, found to have built-up inside on-board components, wherever there are gaps, welds, connectors, or in joints and gaskets.
3. Cleaning of truck internals: The on-board water pumps are fed by, and feed, an intricate series of pipes, lines and injectors. Cross contamination has been found to be common, and the pumps and feed lines internal to the truck need to be cleaned.
4. Cleaning of delivery systems: Delivery of foam/water mix can be through on-board hose reels, direct to hose systems from the main delivery panels on the side of the trucks, or from what is termed 'the monitor', a roof-mounted delivery system. Each of these also needs to be decontaminated.
5. Purging of truck internal lines: A specially designed multi-part manifold is connected to the truck and the internal pump systems. Lines and foam injectors are purged.
6. Cleaning of Onboard components: Truck-mounted hose reels and monitor are decontaminated by flushing with clean water. Ground-spray systems are also flushed. Detachable components are decontaminated separately. Finally, the whole appliance is pressure washed. The interior voids on the truck, where the tanks and pumps sit, is also pressure washed. All washings are collected using a wet-vac system, for subsequent treatment.
7. Cleaning of Removable components: Each truck also has a series of removable components such as fire-fighting hoses, connectors, uptake and transfer hoses that need to be decontaminated.
8. Hose Decontamination: Fire-fighting hoses are decontaminated both externally and internally using a series of specially design hose-washing units. Several lengths of hose are connected to a high-pressure water recycling unit for internal decontamination. This device has a 5,000 litre water tank and a pump capable of high pressure delivery

According to FRV, the key to successful decontamination is correct sequencing of operations, and detailed recording of each stage of operations. Each truck decontamination can create between 6,000 - 8,000 liters of wastewater. Wastewater is re-concentrated by passing through a series of activated carbon filters (GAC). It has been possible to strip out the PFAS foam from the waste and achieve sub part-per billion results in the treated wastewater, enabling this to be disposed to trade waste, with the carbon sent for high temperature destruction.

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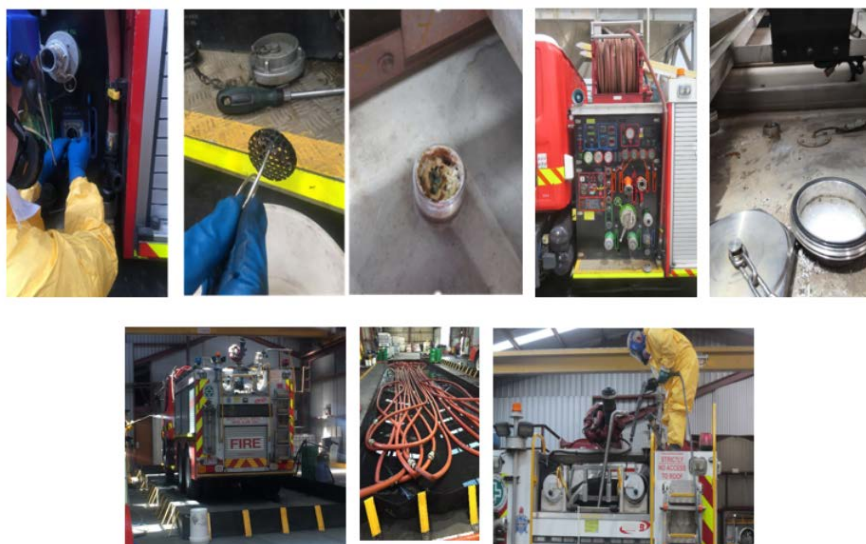


Figure 22: The Decontamination Process – in pictures (taken from (Fire-Rescue-Victoria 2021))

4.15.1. Remaining PFAS concentrations

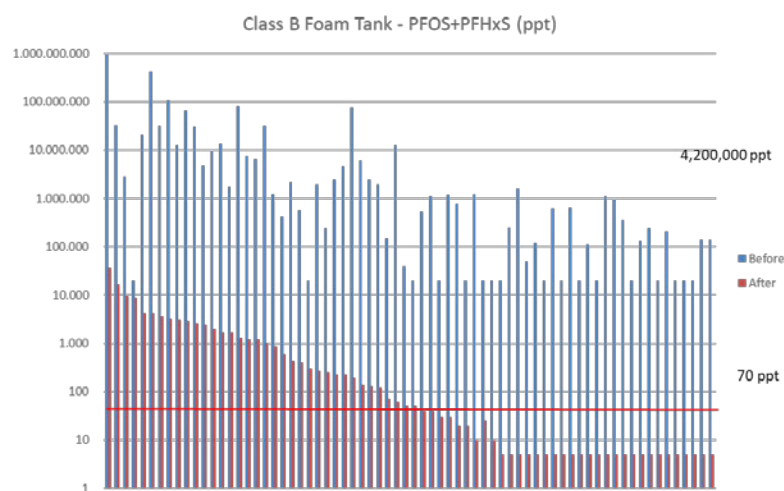


Figure 23: Achieved PFAS levels after decontamination according to the protocol by FVR, before (blue) and after (red) (taken from (Fire-Rescue-Victoria 2021))

For the remaining PFAS levels, a two-tier decontamination has been chosen. FRV firefighting urban operations and routine training are two very different scenarios. In urban operations, a firefighter might deploy foam in one fire in every 20–50. Water is deployed into a highly modified urban environment. In routine training the same location (a fire training facility) is

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repeatedly exposed, on a daily basis, to water deposition from fire appliances. If that water was even slightly contaminated, there was a risk of progressive build-up of PFAS in the soil and run-off. For that reason, the target for fire trucks for training purposes became “drinking water standard”.

For a decontaminated fire appliance, that was translated as meaning no sample exceeded 70 parts per trillion for PFAS.

The MFB commissioned a risk exposure pathway analysis that determined PFAS thresholds levels for both training and operations. Based on this the remaining PFAS concentrations have been set and can also be reached using the described protocol, see below Table 4.

Table 2: PFAS residual thresholds (taken from (Fire-Rescue-Victoria 2021))

Endorsed Residual Threshold	FRV Appliance Limits	PFAS	Sum of PFOA	Sum of PFHxS and PFOS
Derived Human Health Levels			21,800 ppt (Parts Per Trillion)	413,000 ppt (Parts Per Trillion)
FIRE FIGHTING OPERATIONS LEVEL (Green Sticker)			21 ug/l	413 ug/l
VEMTC (Victorian Emergency Management Training Complex) Craigieburn Levels			70 ppt (Parts Per Trillion)	70 ppt (Parts Per Trillion)
FIRE FIGHTING TRAINING LEVEL (Blue Sticker)			0.07 ug/l	0.07 ug/l

4.15.2. Costs

There is no information available on costs for this technique.

4.15.3. Additional information and available case studies

Since 2016, over 145 FRV and CFA firefighting appliances and over 150 kms (over 5,500 lengths), of firefighting hoses have gone through this PFAS decontamination process to below the established thresholds and have been successfully cleaned and returned back into commission for operational use. This work has been conducted in a quantitatively measurable manner by independent 3rd parties.

4.16. Cleaning protocol by FPA Australia

4.16.1. Background

Fire Protection Association Australia (FPA Australia) is the national peak body for fire safety, providing information, services and education to the fire protection industry and the community. According to an information bulletin provided by FPA Australia, changing from a foam containing PFOS or PFOA to a US EPA PFOA Stewardship compliant C6 foam, a REACH Regulation (EU) 2017/1000 compliant C6 foam or an F3 foam will require thorough washing

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of the tank and concentrate sections of pipework (including proportioners) until no frothing is visible (FPA-AUS 2020). It also requires collection, remediation and safe disposal of all effluent from this washing process.

Cleaning Procedure

FPA Australia recommends the following process when cleaning foam tanks or changing out existing C8 foams:

1. Decant existing C8 foam into suitable storage containers, which are also banded and clearly marked for incineration/destruction.
2. Thoroughly flush system with water and collect effluent in suitable storage containers/tankers, identifying contents. The use of hot water may facilitate cleaning.
3. Using suitable remediation technologies, flushed foam solution and effluent should be treated to concentrate the PFAS into as small a volume as practical and should be held separately and labelled prior to disposal/destruction.
4. Analyse clean water for residual PFAS levels, before any release for re-use to the sewer/environment to ensure local regulatory requirements are met.
This is likely to require temporary storage in large clean tanks without any previous PFAS usage or potential pre-existing PFAS contamination.
5. Send concentrated PFAS containing materials for disposal/destruction in accordance with local regulatory requirements.

4.16.2. Remaining PFAS concentrations

To avoid the possibility of contamination, the tank should not be filled with the replacement foam until the results of this testing are available and confirm sufficiently low levels acceptable to the local environmental regulator. It is recommended a sample of the “clean” effluent be tested by a NATA accredited laboratory for traces of PFOS/PFHxS/PFOA to determine a baseline level of contamination for future reference and to confirm the storage is essentially “PFOS, PFHxS and PFOA free” down to the levels specified in the Queensland Policy.

4.16.3. Costs

There is no information available on costs for this procedure.

4.16.4. Additional information and available case studies

There is no information available on case studies.

4.17. Cleaning protocol by the Australian DoD

4.17.1. Background

The Aircraft Rescue & Firefighting (ARFF) foam transition project will transition of all Army, Air Force and Broad spectrum firefighting vehicles to a suitable Fluorine Free Foam (F3) product (DoD-AUS 2020b). The ARFF Vehicle Foam Transition Sub Working Group will manage this project under delegation from the One Defence Firefighting Foam Management Working Group. As seen in the figure (Figure 22) below, the cleaning procedure relies on the set up of 10 cleaning hubs, where over 100 vehicles will be cleaned. The procedure and the description are very detailed and equipped with further documentation by photos. In the following only a brief overview will be given.

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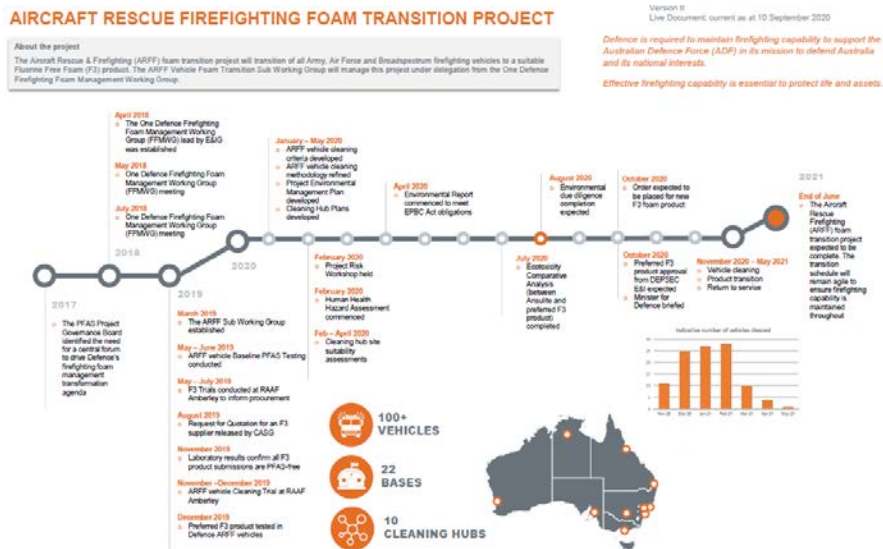


Figure 24: Overview on the Aircraft Rescue & Firefighting (ARFF) foam transition project (DoD-AUS 2020a)

Cleaning Procedure

FPA Australia recommends the following process when cleaning foam tanks or changing out existing C8 foams:

1. Decanting Aqueous Film Forming Foam (AFFF). ARFF vehicles will be decanted of AFFF prior to chain of custody being taken by the Hub Supervisor, and cleaning activities comm. Continuous flush.
2. Sample baseline
3. Vehicle CES soaking
4. Outlet and hose flushing
5. Sample for validation
6. Re-fill with F3. ARFF vehicles will be re-filled with F3 upon completion of the required cleaning activities set out in step 4. The Hub Supervisor will apply a colour coded zip tie to cleaned CES items associated with the vehicle to identify them as F3 only.
7. Proportioner Calibration and Return to Service Testing (RTS): The User Units will conduct vehicle foam performance tests (including proportioner calibration) inside, or at, the designated foam test facility or area as per existing testing arrangements.
8. Restart next vehicle
9. Vehicle validation against cleaning criteria There is a checklist, which needs to be checked before the vehicle can leave the hub.

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Figure 25: Cleaning procedure phases in accordance to the Queensland DoD (DoD-AUS 2020c)

4.17.2. Remaining PFAS concentrations

There is no information available for the remaining PFAS concentration.

4.17.3. Costs

There is no information available on costs for this procedure.

4.17.4. Additional information and available case studies

There is no information available on case studies.

4.18. Cleaning protocol by Werkfeuerwehrverband Deutschland (WFVD)

According to WFVD's homepage²⁴², the plant and company fire departments as well as the company fire protection officers have a special task within the framework of the organization serving fire protection.

In addition to the general fire protection tasks, the company fire protection organization must take into account the special company risks. Preventive fire protection, hazard prevention and company rescue services are of particular importance.

As a result of the need to adapt to company-specific conditions, the principles and guidelines established for public fire departments cannot be transferred to plant and company fire departments without further ado.

The plant and company fire departments as well as the company fire protection officers therefore need their own organization for the purpose of representing their interests and exchanging experience.

²⁴² See [here](#), last accessed 24.03.2021

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Now that the relevant organizations have largely been formed at the level of the German states, the "Bundesverband Betrieblicher Brandschutz/Werkfeuerwehrverband Deutschland e.V.", hereinafter referred to as WFVD, is the appropriate representative body.

4.18.1. Background

In 2014 it was noticed that PFAS levels in the foam concentrate of two fire apparatus at an industrial facility is higher than expected (for example 30,000µg/kg 6:2FTS). The purchased foam concentrate used in this tank was a C6 based AFFF (not based on PFOS, see Figure 3 for a PFAS analysis of the new product) and it did not exceed the threshold of 10,000µg/kg PFOS. However, the foam concentrates in the tanks of the of two fire apparatus exceeded PFOS levels. This was traced back to a cross contamination from a PFOS-based foam concentrate (3M Lightwater) that was in the same foam concentrate tanks before. It was supposed that during transition from C8 (PFOS based) foam to C6 (PFHxA precursor based) foam, the tanks were not cleaned sufficiently. Residues of 3M Lightwater contained high amounts of PFOS and contaminated the new PFOS-free AFFF.

It was decided to develop a foam concentrate tank cleaning procedure, clean the tanks accordingly and transition to fluorine free foam.

According to WFVD, from these cases it can be concluded that the described foam concentrate tank cleaning procedure is an effective method to clean tanks for firefighting foam concentrate when transitioning from PFAS-based to fluorine free foam. It is simple enough to be carried out by fire brigades themselves or for example by companies that specialize in industrial cleaning. It sufficiently reduces PFAS levels below applicable standards and is adjustable in case the results do not meet expectations.

Cleaning Procedure

The foam concentrate tank cleaning procedure is a relatively simple process that in many cases can be carried out by fire services themselves. Basically, it comprises a series of flushing with water, after the tank is emptied. Main challenge in this process is to avoid spills and contamination of equipment outside the foam concentrate tank. During step 2 and 3 the residues of the foam concentrate will cause foaming inside the tank. The overflow of that foam should be avoided to not cause any contamination outside of the tank.

Further attention should be paid to a proper disposal of the old foam concentrate and any rinsing water. The standard disposal method would be high temperature incineration in a facility that is able to handle PFAS waste.

WFVD recommends the following foam concentrate tank cleaning procedure:

1. Step 1:
 - a. Empty foam concentrate tank, pump and piping
 - b. Dispose foam agent through high temperature incineration
2. Step 2:
 - a. Fill tank with warm water (60-70°C) (half full to avoid overflow of foam)
 - b. Drive with apparatus for a 30minutes to allow contact of water with the whole inner tank surface
 - c. Pump water with foam pump in a loop for about 30 minutes
 - d. Empty tank, pump and piping
 - e. Destroy foam inside tank with water and a very fine nozzle and empty tank again
 - f. Dispose water through high temperature incineration
3. Step 3:
 - a. Repeat step 2 one time

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4. Step 4:
 - a. Fill tank with water
 - b. Pump water with foam pump in a loop for about 30 minutes
 - c. Take a water sample
 - d. Analyse water sample for PFAS
 - e. Repeat Step 3 if results of PFAS analysis are not sufficient
 - f. Dispose water through high temperature incineration
5. Step 5
 - a. Drain any rinsing water from tank, pump and any pipes
 - b. Dry tank as good as practically possible
 - c. Fill tank with new foam concentrate

4.18.2. Remaining PFAS concentrations

According to WFVD, the efficacy of the foam concentrate tank cleaning procedure can be assessed when looking at Figure 24 and Figure 25.

The highest remaining PFAS-substances reported in Figure 24 are 6:2 FTS with 0,98 µg/L (0.00098 ppm) and PFOS with 0,81 µg/L (0.00081 ppm). The highest remaining PFAS-substances reported in Figure 25 are PFOS with 42 µg/L (0.042 ppm) and PFOA with 1,2 µg/L (0.0012 ppm). If all reported PFAS-substances are added a remaining concentration of 57,5 ppm (0.057 ppm) is measured.

These are PFAS analyses of the rinsing water from step 4 of the procedure. As these are analyses for PFAS in water the detection limit for PFAS is lower than in the analyses for PFAS in foam concentrate. The analyses show that cleaning is effective with dilution factors varying between 100 and 100,000. While PFAS can still be detected in the rinsing water in all cases they are lower than current applicable thresholds for PFOS (not further commented by the stakeholder but most likely 10 ppm according to POP-regulation) and PFOA (not further commented by the stakeholder). If the results do not meet expectations step 2/3 can be repeated until levels are sufficiently low. It has to be noted that the water analyzed in step 4 will also be disposed and that PFAS levels can be assumed to be even lower when the new foam concentrate is filled in.

Beschreibung	Messwert	Einheit	Verfahren
4H-Perfluordecansulfonat (8:2 FTS)	0,045	µg/L	
4H-Perfluorhexansulfonat (4:2 FTS)	< 0,01	µg/L	
4H-Perfluoroctansulfonat (6:2 FTS)	0,98	µg/L	
Perfluorbutansäure	0,012	µg/L	
Perfluorbutansulfonsäure	0,039	µg/L	
Perfluordecansäure	< 0,01	µg/L	
Perfluorheptansäure	0,014	µg/L	
Perfluorhexansäure	0,097	µg/L	
Perfluorhexansulfonsäure	0,19	µg/L	
Perfluornonansäure	< 0,01	µg/L	
Perfluoroctansäure (PFOA)	0,037	µg/L	
Perfluoroctansulfonsäure (PFOS)	0,81	µg/L	
Perfluorpentansäure	0,011	µg/L	

Figure 26: PFAS Analysis of rinsing water from apparatus "TMB" from step 4 of tank cleaning procedure (note, that the detection limit is lower as this is an analysis for PFAS in water as opposed to PFAS in foam concentrate in other figures)

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4H-Perfluordecansulfonat (8:2 FTS)	0,19	µg/L		
4H-Perfluorhexansulfonat (4:2 FTS)	< 0,01	µg/L		
4H-Perfluorooctansulfonat (6:2 FTS)	1,7	µg/L		
Perfluorbutansäure	0,31	µg/L		
Perfluorbutansulfonsäure	0,96	µg/L		
Perfluordecansäure	< 0,01	µg/L		
Perfluorheptansäure	0,39	µg/L		
Perfluorhexansäure	1,5	µg/L		
Perfluorhexansulfonsäure	11	µg/L		
Perfluornonansäure	< 0,01	µg/L		
Perfluorooctansäure (PFOA)	1,2	µg/L		
Perfluorooctansulfonsäure (PFOS)	42	µg/L		
Perfluorpentansäure	0,45	µg/L		

Figure 27: PFAS Analysis of rinsing water from apparatus "PTLF II" from step 4 of tank cleaning procedure (Note 1: The detection limit is lower as this is an analysis for PFAS in water as opposed to PFAS in foam concentrate in other figures Note 2: This apparatus is also referred to as "TroTSLF 2" or "PTLF 2")

4.18.3. Costs

Costs for the cleaning of a foam concentrate tank of a fire apparatus highly depend on disposal costs for the foam concentrate and flush water, summing up to 50% of the total costs in this example (4000 €). It is estimated that the volume of the flush water is three times that of the tank volume. Other costs, like work hours are likely to be independent from tank size (unless deviating to a greater extent from this example). In this case study the work was done by the industrial fire brigade itself, so that no external costs arose for work hours.

Disposal of foam concentrate for 1 m ³	500€/m ³	500€
Disposal of flush water (3m ³)	500€/m ³	1500€
Work hours (2 people, 10h each)	50€/h	1000€
IBC totes for foam concentrate and flush water	150€/piece	600€
Small equipment estimate (PPE, contaminated hoses, etc.)	400€	400€
Total		4000€

Figure 28: Estimated costs for the cleaning of a 1 m³ foam concentrate tank with the described cleaning procedure

4.18.4. Additional information and available case studies

- Three years after the cleaning of the tanks, the foam concentrate was analysed for PFAS again. Except for one PFAS in the apparatus all PFAS are below the detection limit and, most important, below the applicable threshold for PFOS and PFOA. The reason for the 56µg/kg of 6:2 FTS in apparatus "TMB" are not known for sure. Possible explanations are: Cross contamination from residues of old foam concentrate, contamination of the sample or measuring error.
- The procedure is also explained in a video available at Youtube ([English](#) and [German](#) version). The stakeholder reported there are some mistakes concerning the values in the English version.

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