

THE PRESENCE OF PFAS IN WASTES AND RELATED IMPLICATIONS ON THE CURRENT AND PROPOSED EUROPEAN REGULATORY FRAMEWORK: A SYSTEMATIC CRITICAL REVIEW

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SUPPLEMENTARY MATERIAL

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S1. Documents considered eligible for the data extraction

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Table S1. Collection of regulation limits or proposal of limits on PFASs which have or may have impacts on waste management.

Chemicals	Limits	State of the regulation	Implications in the waste management field	Reference
<p>Perfluorooctane sulfonic acid and its derivatives (PFOS) C₈F₁₇SO₂X (X = OH, Metal salt (O-M+), halide, amide, and other derivatives including polymers)</p> <p>For more information on the list of substances see the work of Department for Environment, Food and Rural Affairs Persistent, UK (2015)</p>	<p>ANNEX IV. List of substances subject to waste management provisions set out in Article 7</p> <ul style="list-style-type: none"> • ≤ 50 mg/kg (0.005 % by weight). <p>ANNEX V. Disposal and recovery under Article 7(2)</p> <ul style="list-style-type: none"> • ≤ 50 mg/kg (0.005 % by weight). 	<input checked="" type="checkbox"/> Existing limits <input type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • disposal or recovery operations that may lead to recovery, recycling, reclamation or re-use of wastes • classification of waste (potential) • control and traceability following hazardous waste requirements 	<p>Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on Persistent Organic Pollutants and amendments. ANNEX IV. List of substances subject to waste management provisions set out in Article 7 ANNEX V. Disposal and recovery under Article 7(2)</p>
<p>Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds</p> <p>For more information on the list of substances including salts and related compounds see UNEP, 2022 and OECD. 2018</p>	<p>ANNEX IV. List of substances subject to waste management provisions set out in Article 7</p> <ul style="list-style-type: none"> • ≤1 mg/kg for PFOA and its salts, • ≤ 40 mg/kg for the sum of PFOA-related compounds <p>ANNEX V. Disposal and recovery under Article 7(2)</p> <ul style="list-style-type: none"> • ≤50 mg/kg for PFOA and its salts • ≤2000 mg/kg for PFOA-related compounds; 	<input checked="" type="checkbox"/> Existing limits <input type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • disposal or recovery operations that may lead to recovery, recycling, reclamation or re-use of wastes • classification of waste (potential) • control and traceability following hazardous waste requirements 	<p>Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on Persistent Organic Pollutants and amendments. ANNEX IV. List of substances subject to waste management provisions set out in Article 7 ANNEX V. Disposal and recovery under Article 7(2)</p>
<p>Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds</p> <p>For more information on the list of substances including salts and related compounds see UNEP, 2019 and OECD. 2018</p>	<p>ANNEX IV. List of substances subject to waste management provisions set out in Article 7</p> <ul style="list-style-type: none"> • ≤1 mg/kg for PFHxS and its salts • ≤40 mg/kg for the sum of PFHxS-related compounds <p>ANNEX V. Disposal and recovery under Article 7(2)</p> <ul style="list-style-type: none"> • ≤50 mg/kg for PFHxS and its salts; • ≤2000 mg/kg for PFHxS-related compounds 	<input checked="" type="checkbox"/> Existing limits <input type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • disposal or recovery operations that may lead to recovery, recycling, reclamation or re-use of wastes • classification of waste (potential) • control and traceability following hazardous waste requirements 	<p>Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on Persistent Organic Pollutants and amendments. ANNEX IV. List of substances subject to waste management provisions set out in Article 7 ANNEX V. Disposal and recovery under Article 7(2)</p>

Chemicals	Limits	State of the regulation	Implications in the waste management field	Reference
<p>Perfluorooctane sulfonic acid and its derivatives (PFOS) $C_8F_{17}SO_2X$ (X = OH, Metal salt (O-M+), halide, amide, and other derivatives including polymers)</p> <p>For more information on the list of substances see the work of Department for Environment, Food and Rural Affairs Persistent, UK (2015)</p>	<p>Regulation (EU) 2019/1021. Annex I</p> <ul style="list-style-type: none"> • ≤ 10 mg/kg (0.001 % by weight) where PFOS are present in substances or in mixtures. • ≤ 1000 mg/kg (0.1 % by weight) in semi-finished products or articles or parts thereof calculated with reference to the mass of structurally or micro-structurally distinct parts that contain PFOS or, for textiles or other coated materials, if the amount of PFOS is lower than 1 $\mu\text{g}/\text{m}^2$ of the coated material. 	<input checked="" type="checkbox"/> Existing limits <input type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • Procedure for end-of waste 	<p>POPs under the Stockholm Convention (decisions SC-4/17; SC-9/4) Annex "B". Restriction (UN Environment Programme and Stockholm Convention, 2023)</p> <p>Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on Persistent Organic Pollutants and amendments. ANNEX I. Part A. Substances listed in the Convention and in the Protocol as well as substances listed only in the Convention</p>
<p>Perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds</p> <p>For more information on the list of substances including salts and related compounds see UNEP, 2022 and OECD. 2018</p>	<p>Regulation (EU) 2019/1021. Annex I</p> <ul style="list-style-type: none"> • ≤ 0.025 mg/kg (0.000025 % by weight) where PFOA or any of its salts are present in substances, mixtures or articles. • ≤ 1 mg/kg (0.0001 % by weight) where any individual PFOA-related compound or a combination of PFOA-related compounds are present in substances, mixtures or articles. • ≤ 20 mg/kg (0.002 % by weight) where PFOA-related compounds are present in a substance to be used as a transported isolated intermediate. • ≤ 1 mg/kg (0.0001 % by weight) where PFOA and its salts are present in polytetrafluoroethylene (PTFE) micropowders produced by ionising irradiation or by thermal degradation as well as in mixtures and articles for industrial and professional uses containing PTFE micropowders until 18 August 2023. 	<input checked="" type="checkbox"/> Existing limits <input type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • Procedure for end-of waste 	<p>POPs under the Stockholm Convention (decision SC-9/12). Annex "A". Elimination (UN Environment Programme and Stockholm Convention, 2023)</p> <p>Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on Persistent Organic Pollutants and amendments. ANNEX I. Part A. Substances listed in the Convention and in the Protocol as well as substances listed only in the Convention</p>
<p>Perfluorohexane-1-sulphonic acid (PFHxS), its salts and related substances:</p> <ul style="list-style-type: none"> • Perfluorohexane sulfonic acids with the formula $C_6F_{13}SO_3H$, their salts and any combinations thereof; • Any substance having a perfluoroalkyl group C_6F_{13}- directly attached to a sulfur atom. <p>For more information on the list of substances including salts and related compounds see UNEP, 2019 and OECD. 2018</p>	<p>Proposed limits for the restriction of PFHxS, its salts and PFHxS-related substances when they are present in another substance, as a constituent, a mixture, an article or any parts thereof (Norwegian Environment Agency, 2019):</p> <ul style="list-style-type: none"> • ≤ 0.025 mg/kg (25 ppb) for the sum of PFHxS and its salts • ≤ 1 mg/kg (1000 ppb) for the sum of PFHxS related substances. 	<input type="checkbox"/> Existing limits <input checked="" type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • Procedure for end-of waste 	<p>POPs under the Stockholm Convention (decision SC-10/13). Annex "A". Elimination (UN Environment Programme and Stockholm Convention, 2023)</p> <p>This class of chemical is currently being assessed for a restriction under REACH (ECHA, 2023a)</p>

Chemicals	Limits	State of the regulation	Implications in the waste management field	Reference
<p>Perfluorocarboxylic Acids Containing 9 to 14 Carbon Atoms in the Chain (C9-C14 PFCAs), their Salts and C9-C14 PFCA-Related Substances</p> <p>For more information on the list of substances including salts and related compounds see ECHA, 2017.</p>	<p>Limits for the restriction of Perfluorocarboxylic Acids Containing 9 to 14 Carbon Atoms in the Chain (C9-C14 PFCAs), their Salts and C9-C14 PFCA-Related Substances when they are present in another substance, as a constituent, a mixture, an article or any parts thereof:</p> <ul style="list-style-type: none"> • ≤ 0.025 mg/kg (25 ppb) for the sum of C9-C14 PFCAs and their salts • ≤ 0.26 mg/kg (260 ppb) ppb for the sum of C9-C14 PFCA-related substances • ≤ 10 mg/kg (10 ppm) for the sum of C9-C14 PFCAs, their salts and C9-C14 PFCA related substances, where they are present in a substance to be used as a transported isolated intermediate 	<input checked="" type="checkbox"/> Existing limits <input type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • Procedure for end-of waste 	<p>Regulation (EU) 2021/1297 Amending Annex XVII to REACH as regards Perfluorocarboxylic Acids Containing 9 to 14 Carbon Atoms in the Chain (C9-C14 PFCAs), their Salts and C9-C14 PFCA-Related Substances. This law has become effective on February 25, 2023.</p> <p>Regulation (EC) 1907/2006 on Registration, Evaluation, Authorization and Restriction of Chemicals (REACH, consolidated version to July 2021) Annex XVII. Restrictions on the manufacture, placing on the market and use of certain dangerous substances, mixtures and articles.</p> <p>in 2021 Canada proposed to consider long-chain perfluorocarboxylic acids (C9-C21 PFCAs) for inclusion in the Stockholm Convention</p>
<p>Undecafluorohexanoic acid (PFHxA), its salts and related substances</p>	<p>Proposed limits for the restriction of undecafluorohexanoic acid (PFHxA), its salts and related substances (BAuA et al., 2019) when they are present in another substance, as a constituent, a mixture, an article:</p> <ul style="list-style-type: none"> • ≤ 0.025 mg/kg (25 ppb) for for the sum of PFHxA and its salts • ≤ 1 mg/kg (1000 ppb) for the sum of PFHxA- related substances. 	<input type="checkbox"/> Existing limits <input checked="" type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • Procedure for end-of waste 	<p>This class of chemical is currently being assessed for a restriction under REACH (ECHA, 2023b)</p>
<p>Per- and polyfluoroalkyl substances (PFASs) defined as any substance that contains at least one fully fluorinated methyl (CF₃-) or methylene (-CF₂-) carbon atom (without any H/Cl/Br/I attached to it)</p>	<p>Proposed limits for the restriction of PFASs (BAuA et al., 2023) when they are present in another substance, as a constituent, a mixture, an article:</p> <ul style="list-style-type: none"> • ≤ 0.025 mg/kg (25 ppb) for any PFAS as measured with targeted PFAS analysis (polymeric PFASs excluded from quantification) • ≤ 0.25 mg/kg (250 ppb) for the sum of PFASs measured as sum of targeted PFAS analysis, optionally with prior degradation of precursors (polymeric PFASs excluded from quantification) • ≤ 50 mg/kg (50 ppm) for PFASs (polymeric PFASs included). If total fluorine exceeds 50 mg F/kg the manufacturer, importer or downstream user shall upon request provide to the enforcement authorities a proof for the fluorine measured as content of either PFASs or non-PFASs. 	<input type="checkbox"/> Existing limits <input checked="" type="checkbox"/> Proposed limits	<ul style="list-style-type: none"> • Procedure for end-of waste 	<p>This class of chemical is currently being assessed for a restriction under REACH (ECHA, 2023c)</p>

Table S.2. Descriptive statistics of the concentration data gathered for the category “Paper and cardboard waste”.

Parameter	n	Median	Range	Q3	90%	95%
	-	ppb				
PFOA	215	0.918	0.029 - 2356	2.788	8.881	48.800
C9-C14 PFASs	505	0.610	0.005 - 2111	0.950	5.036	29.650
PFOS	153	0.610	0.005 - 36.992	3.010	5.019	7.260
PFHxS	74	0.610	0.005 - 7.45	0.610	0.610	0.610
Other PFASs	1733	0.610	0.002 - 12700	0.900	7.412	78.160

Table S.3. Descriptive statistics of the concentration data gathered for the category “Textile and leather waste”.

Parameter	n	Median	Range	Q3	90%	95%
	-	ppb				
PFOA	101	0.555	0.039 - 57.2	0.875	6.000	12.400
C9-C14 PFASs	343	0.140	0.08 - 530	0.635	0.912	2.834
PFOS	108	0.660	0.01 - 8849	1.408	12.990	143.963
PFHxS	101	0.615	0.027 - 1085	0.870	2.500	5.950
Other PFASs	835	0.620	0.01 - 40900	0.937	7.124	150.000

Table S.4. Descriptive statistics of the concentration data gathered for the category “Plastic waste”.

Parameter	n	Median	Range	Q3	90%	95%
	-	ppb				
PFOA	39	0.045	0.045 - 3.46	0.080	0.744	2.380
C9-C14 PFASs	174	0.090	0.01 - 0.84	0.125	0.140	0.287
PFOS	46	0.080	0.01 - 35.5	1.698	2.935	4.993
PFHxS	35	0.055	0.01 - 0.34	0.080	0.086	0.222
Other PFASs	319	0.080	0.01 - 16.9	0.080	0.410	0.827

Table S.5. Descriptive statistics of the concentration data gathered for the category “Metal waste and metal scraps”.

Parameter	n	Median	Range	Q3	90%	95%
	-	ppb				
PFOA	5	9.390	1 - 14.03	11.350	12.958	13.494
C9-C14 PFASs	9	0.610	0.12 - 2.7	1.130	2.180	2.440
PFOS	11	4.650	1 - 11.3	9.035	9.190	10.245
PFHxS	3	0.200	0.18 - 0.21	0.205	0.208	0.209
Other PFASs	27	1.090	0.01 - 5065.6	1.535	17.048	52.289