

1 **Are fluoropolymers really of low concern for human and environmental health and separate**  
2 **from other PFAS?**

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## 23 **Abstract**

24 Fluoropolymers are a group of polymers within the class of per- and polyfluoroalkyl substances  
25 (PFAS). The objective of this analysis is to evaluate the evidence regarding the environmental  
26 and human health impacts of fluoropolymers throughout their life cycle(s). Production of some  
27 fluoropolymers is intimately linked to the use and emissions of legacy and novel PFAS as  
28 polymer processing aids. There are serious concerns regarding the toxicity and adverse effects  
29 of these processing aids on humans and the environment. A variety of other PFAS, including  
30 monomers and oligomers, are emitted during the production, processing, use and end-of-life  
31 treatment of fluoropolymers. There are further concerns regarding the safe disposal of  
32 fluoropolymers and their associated products at the end of their life cycle. While recycling and  
33 reuse of fluoropolymers is performed on some industrial waste, there are only limited options  
34 for their recycling from consumer products. The evidence reviewed in this analysis does not  
35 find a scientific rationale for concluding that fluoropolymers are of low concern for  
36 environmental and human health. Given fluoropolymers' extreme persistence, emissions  
37 associated with their production, use, and disposal, and high likelihood for human exposure to  
38 PFAS, their production and uses should be curtailed except in cases of essential use.

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40

41 **Introduction**

42 The class of per- and polyfluoroalkyl substances (PFAS) consists of polymers and non-polymers.<sup>1</sup>

43 Most regulatory and academic attention so far has focused on the non-polymeric PFAS, either  
44 perfluorinated or polyfluorinated alkyl substances. Within the groups of polymeric PFAS, there  
45 are fluoropolymers, side-chain fluorinated polymers, and poly- or perfluoropolyethers.

46  
47 As defined by Buck et al. (2011), “fluoropolymers” represent a distinct subset of fluorinated  
48 polymers, based on a carbon-only polymer backbone with F atoms directly attached to it, e.g.,  
49 polytetrafluoroethylene (PTFE).<sup>1</sup> In this analysis, we focus on fluoropolymers, but do not assess  
50 concerns about other fluorine-containing polymers, namely side-chain fluorinated polymers,  
51 and poly- or perfluoropolyethers. The group of fluoropolymers is dominated by PTFE; combined  
52 with fluorinated ethylene propylene (FEP), ethylene tetrafluoroethylene (ETFE) and  
53 tetrafluoroethylene-copolymers; they account for around 75% of the fluoropolymer market.<sup>2</sup>  
54 Other important fluoropolymers include polyvinylidene fluoride (PVDF), polyvinyl fluoride (PVF)  
55 and fluoroelastomers. One additional fluoropolymer that is discussed in this policy analysis is  
56 the functionalized fluoropolymer Nafion<sup>®</sup> (produced by Chemours), which is a  
57 tetrafluoroethylene-based fluoropolymer-copolymer incorporating perfluorovinyl ether groups  
58 terminated with sulfonate groups. A review by Gardiner (2015) includes a more complete  
59 overview of the different types of fluoropolymers.<sup>3</sup> The fluoropolymer industry produced  
60 320 300 tonnes of fluorinated plastic materials in 2018<sup>4</sup>, and production is steadily increasing.<sup>3</sup>  
61 By 2018 the global fluoropolymer industry was expected to be at \$10 billion per annum.<sup>3</sup>

62

63 Here we evaluate the evidence regarding the environmental and health impacts of  
64 fluoropolymers. Our analysis was prompted by a recent suggestion that fluoropolymers should  
65 be considered as polymers of low concern (PLC).<sup>2</sup> According to the Organization for Economic  
66 Cooperation and Development (OECD), “polymers of low concern are those deemed to have  
67 insignificant environmental and human health impacts”.<sup>5</sup> The PLC status of a material leads to  
68 exemptions for manufacturers from requirements under the legal chemicals management  
69 frameworks in some jurisdictions.<sup>6</sup>

70  
71 The PLC concept is currently derived from the characteristics of finished polymers but does not  
72 cover problems occurring during production and disposal. In recognition of the potential risks  
73 posed by PFAS-related polymers, the U.S. Environmental Protection Agency has denied PLC  
74 exemptions for fluorinated side-chain polymers, but has not acted on fluoropolymers per se.<sup>7</sup>

75  
76 More recently, in 2019, the Industry-led European Centre for Ecotoxicology and Toxicology of  
77 Chemicals (ECETOC) developed the Conceptual Framework for Polymer Risk Assessment  
78 (CF4Polymers).<sup>8</sup> The CF4Polymers framework provides basic guiding principles to be considered  
79 in assessing potential ecological and human health hazards and risks posed by polymer  
80 products. Unlike the PLC concept, CF4Polymers also considers specific life cycle stages of  
81 polymer products and their associated routes of exposure. The CF4Polymers polymer risk  
82 assessment thus appears sufficiently flexible to allow consideration of all potential chemical  
83 hazards at each life stage of a fluoropolymer. However, the authors of the CF4Polymers  
84 framework support the PLC approach as a means of streamlining the polymer risk assessment.

85 They specifically support the findings of Henry et al.<sup>2</sup> and state that they are “...unaware of  
86 scientific evidence to justify generally assigning fluoropolymers the same level of regulatory  
87 concern as other PFAS”.<sup>8</sup>

88  
89 A fluoropolymer as a finished product could technically meet the definitions of a PLC, but still  
90 pose significant concerns to human health and the environment due to emissions occurring  
91 during the life cycle (Figure 1). A well-known case where this occurs is the release of processing  
92 aids during the manufacture of some fluoropolymers. The pollution caused by emissions of low-  
93 molecular-weight PFAS used as polymer processing aids (i.e., emulsifiers, dispersants and  
94 surfactants at large) for the manufacture of some types of fluoropolymers has received  
95 considerable attention.<sup>9–11</sup>

96  
97 Fluoropolymers are very diverse in how they are produced (as granulates, fine powders or  
98 aqueous dispersions, through emulsion or suspension polymerization, with different grades),  
99 shipped, and used, which renders generic judgements on their behavior and characteristics  
100 difficult. For example, some fluoropolymers do not require PFAS-based processing aids in their  
101 manufacture (e.g. granular PTFE), whereas other fluoropolymers (e.g. fine powder PTFE and  
102 PVDF) are manufactured using PFAS-based processing aids.

103  
104 In this paper, we identify concerns for environmental and human health resulting from  
105 emissions during fluoropolymer production, processing and disposal. We first review the link

106 between some types of fluoropolymers and PFAS emissions and then turn to more general  
107 concerns associated with (fluoro)polymers.

108

109 **1. History of pollution from fluoropolymer production is closely tied to use of PFAS as**  
110 **polymer processing aids**

111 Low-molecular-weight PFAS have been used for decades as emulsifiers in the polymerization of  
112 some types of fluoropolymer products. The resulting long-term exposure of production  
113 workers, the environment, and nearby neighborhoods to high levels of PFAS polymer  
114 processing aids by fluoropolymer manufacturers is now well documented and has driven much  
115 of the initial action on PFAS control.<sup>12–19</sup>

116 Historically, the most widely used polymer processing aids were the ammonium salts of  
117 perfluorooctanoic acid (PFOA) and perfluorononanoic acid (PFNA).<sup>20,21</sup> The majority of PFOA  
118 and PFNA now in the global environment is a result of the historical use of salts of these  
119 substances as processing aids.<sup>20,22</sup> As a consequence of human and environmental health  
120 concerns, under the US EPA 2010/15 Stewardship Program, eight major manufacturers phased  
121 out PFOA/PFNA in their fluoropolymer production.<sup>23</sup> Many other manufacturers, though, still  
122 utilize PFOA as a processing aid; PFOA emissions have, for example, now widely polluted the  
123 Chinese environment and likely also the Arctic through ocean transport.<sup>24</sup>

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126

## 127 **2. Substitute fluoropolymer processing aids raise similar concerns**

128 Fluoropolymer producers in industrialized countries have moved to substitute PFOA and PFNA  
129 in polymer production with structurally similar alternatives such as per- and  
130 polyfluoroalkylether carboxylic acids (PFECAs).<sup>21,25</sup> These PFECAs are not technically classified as  
131 “long-chain” perfluoroalkyl acids (PFAAs) like PFOA and PFNA, but they have similar physical  
132 and chemical properties (including surfactancy and resistance to degradation) when compared  
133 with the original emulsifiers.<sup>26</sup>

134 One example is the substitution of PFOA by the ammonium salt of hexafluoropropylene oxide  
135 dimer acid (HFPO-DA, CAS 62037-80-3, or GenX) (Figure 2a) for PTFE production. When  
136 released into the environment, GenX, due to similarly high persistence and mobility as its  
137 predecessor PFOA, accumulates in surface water, groundwater, and soil.<sup>27,28</sup> GenX has also  
138 been observed in surface water and drinking water in areas where it is produced, e.g., in North  
139 Carolina<sup>29</sup> and the Netherlands.<sup>12</sup> GenX does not bioaccumulate in animals to the same extent  
140 as PFOA<sup>30</sup>, but has been added to the EU’s Candidate List of Substances of Very High Concern  
141 (SVHC) due to an equivalent level of concern about its very high persistence, mobility in water,  
142 potential for long-range transport, accumulation in plants and observed effects on human  
143 health and the environment.<sup>31</sup>

144 In another example, (the ammonium salt of) PFNA has been substituted with another PFECA  
145 (CAS 329238-24-6) (Figure 2b)<sup>26</sup>, which has since been detected in the surface water near a  
146 fluoropolymer production facility in Italy<sup>32</sup> and in the surface and groundwater near a similar  
147 PVDF facility in West Deptford, New Jersey (US).<sup>33</sup> Another replacement polymer processing

148 aid, cC604, is the ammonium salt of [perfluoro{acetic acid, 2-[(5-methoxy-1)] (Figure 2c). cC604  
149 has been detected in surface and groundwater in the Veneto region in Italy.<sup>34</sup> Also, ammonium  
150 4,8-dioxa-3H-perfluorononanoate (CAS 958445-44-8, ADONA) (Figure 2d) is a PFECA processing  
151 aid that has been detected in the Rhine River in Germany<sup>35</sup> and in the blood of individuals living  
152 near a fluorochemical production facility in this area.<sup>36</sup>

153 These examples demonstrate the similar concern between legacy and replacement  
154 fluoropolymer processing aids mentioned above in terms of environmental exposure,  
155 bioaccumulation and toxicity.<sup>37,38</sup> Many more PFAS with similar structures have been patented  
156 for possible use as fluoropolymer processing aids.<sup>39-41</sup> Thus, even if individual processing aids  
157 are banned, many other PFAS are available with the same functionality and similar concerns  
158 with respect to persistence and human health effects. 3M claimed that modern containment  
159 technologies recapture approximately 98% of polymer processing aids such as PFOA and others  
160 <sup>42</sup>, but it is not clear if the remaining 2% are not of concern. Moreover, independent data are  
161 not available to support their claim.

162

### 163 **3. Monomer, oligomer and synthesis by-product emissions during the production of** 164 **fluoropolymers**

165 Fluoropolymers are made of one or several types of monomers. During the synthesis, incomplete  
166 polymerization will result in residual monomers and oligomers, and smaller 'polymers' with up  
167 to about 100 monomer units. These and other synthesis by-products are not bound to the  
168 polymers and may be released to air upon heating during manufacturing and processing



169 (including sintering) and to water through wastewater streams.<sup>9,13</sup> For example, a series of  
170 polyfluoroalkyl carboxylic acids were discovered near Decatur, AL (US), each differing by 1,1-  
171 difluoroethene, CF<sub>2</sub>H<sub>2</sub>, which was used as a building block for production of PVDF at that site.<sup>13</sup>  
172 Many ultrashort-chain fluorinated by-products are highly volatile, and therefore difficult to  
173 remove in filters or liquid scrubber baths. An example is trifluoromethane (CHF<sub>3</sub>), which has a  
174 boiling point of -82.1 °C and belongs to the group of hydrofluorocarbon (HFC) gases (HFC-23); it  
175 has a 100-year global warming potential of 12400 relative to CO<sub>2</sub>.<sup>43</sup>

176 Various PFAS oligomers were recently detected in the stack emission samples collected from a  
177 fluorochemical production site.<sup>44</sup> A wide range of byproducts of the functionalized fluoropolymer  
178 Nafion has been observed in the environment and found to bioaccumulate in fish<sup>45</sup>, which could  
179 be the result of manufacturing discharges<sup>10</sup>, or losses resulting from Nafion use over time.<sup>46</sup> It is  
180 noted that Nafion does probably not meet the PLC criteria because its sulfonic functional group  
181 can be degraded and lost.

182 Little is known about emissions of airborne fluoropolymer particles and oligomers, another  
183 potential source of PFAS in the atmosphere. Henry et al. (2018) specified the particle size in  
184 fluoropolymer powders to vary between 50 and 250 μm, larger than the harmful particle sizes of  
185 PM<sub>10</sub> and PM<sub>2.5</sub> (10 and 2.5 μm) in terms of harms caused by inhalation.<sup>2</sup> However,  
186 fluoropolymer particles vary in size, and may contain and transport residual  
187 monomers/oligomers long distances from their emission sources.

188

189           **4. Leaching of low-molecular-weight PFAS from fluoropolymers during processing and**  
190           **use**

191   Linked to the use of PFAS as production processing aids (see above), there are concerns  
192   regarding the remaining low molecular weight PFAS in fluoropolymers after production. For  
193   example, Henry et al. (2018) argued that fluoropolymers are not toxic, based on a dataset that  
194   was restricted only to a few fluoropolymer finished products, typically > 100,000 Da.<sup>2</sup>  
195   Concentrations of leachable components reported for those specific fluoropolymer products,  
196   particularly a PTFE fine powder, were labeled “very low” at 1 ppm (i.e., 1 mg/kg)<sup>2</sup>, though  
197   earlier studies reported concentrations of 1-10 ppm in PTFE fine powder and much higher in  
198   PTFE aqueous dispersion (see SI in Wang et al. (2014)<sup>22</sup>). Similar levels of PFAAs (0.3-24 ppm)  
199   were found in personal care products that contained PTFE fine particles (Assuming the  
200   cosmetics contained 1% PTFE, the range of leachables is 0.3 -24 ppm; if the total organofluorine  
201   measurements represented PTFE fine powder, then the range of PFAA-leachables is 15-1,000  
202   ppm).<sup>47</sup>

203   Processing aids and other PFAS residuals, impurities and synthesis by-products are also known  
204   to leach from fluoropolymer products, for example in chromatographic instrumentation,  
205   causing a consistent background signal in analytical chemistry at the ppt level.<sup>48,49</sup> Residuals of  
206   1 ppm may have significant toxicological relevance, given the recently proposed drinking water  
207   guidelines for some PFAS set at 10-100 ng/L in different countries.<sup>50,51</sup>

208   Further, Henry et al. (2018) state that the low residual levels found in the finished PTFE  
209   products that they tested are due in large part to “aggressive” steps taken to wash out residuals

210 and drive off volatiles.<sup>2</sup> Such aggressive treatment raises the question of how these residuals  
211 and volatiles are captured and their releases controlled, or if production by-products become  
212 air or water emissions with potential for human exposure. There is evidence that the drying  
213 step (sintering) of fluoropolymers has led to substantial emissions to air of processing aids at  
214 sites of PTFE production (West Virginia (US) and the Netherlands) and use sites in the US (North  
215 Bennington, VT; Merrimack, NH, Hoosick Falls, NY).<sup>52-54</sup>

216

## 217 **5. Toxicity of fluoropolymer processing aids, monomers and oligomers**

218 Legacy processing aids (i.e., PFOA, PFNA) used to manufacture fluoropolymers are linked to a  
219 wide range of health effects in experimental animal models (causative) and humans  
220 (associative), including certain types of cancer, immunotoxicity, reproductive and  
221 developmental toxicity, liver toxicity, and thyroid disease.<sup>55</sup> HFPO-DA shows a similar toxic  
222 potency in rodents as PFOA<sup>38</sup>, but its pharmacokinetics in humans are still uncertain. Few  
223 reports have been published regarding the potential toxicity of other replacement PFECAs, such  
224 as ADONA<sup>56,57</sup> or the PFECA CAS 329238-24-6<sup>58</sup>, but these replacement chemicals are as  
225 environmentally persistent as the original polymer processing aids.<sup>37</sup> The production of many  
226 fluoropolymers still requires the use of PFAS as surfactants or as monomers, which causes  
227 releases to the environment during manufacture, and thus may pose a risk to human health  
228 and the environment. For example, the so-called "Teflon-flu" or "Polymer fume fever" has been  
229 ascribed to workers exposure to PTFE oligomers during production/manufacturing<sup>59</sup>.

230

## 231           **6. Penetration of cell membranes by macromolecules**

232   While not specific to fluoropolymers, PLC status is partially based on a mass-based cutoff for  
233   cellular uptake (MW of > 1000 Da or 10,000 Da, depending on reactive functional groups). This  
234   was summarized by Henry et al. (2018), who advocated for PLC status of some fluoropolymers  
235   by suggesting “Polymers are too large to penetrate cell membranes”.<sup>2</sup> This position is not  
236   currently supported by the scientific literature related to the bioavailability of similarly sized  
237   micro- and nanoplastics of fluorine-free polymers. Nearly a decade ago, Jiang et al. (2011)  
238   showed that polystyrene nanoparticles of about 100 nm diameter are easily able to enter stem  
239   cells.<sup>60</sup> Similarly, Pitt et al. (2018) reported that 42 nm polystyrene nanoparticles were present  
240   in tissue and organs of maternally and co-parentally exposed F1 embryos/larvae, proving  
241   membrane crossing capabilities of polymer nanoparticles.<sup>61</sup> Polymer nanoparticles with  
242   molecular weights between 12,000 and 21,000 Da have been used to deliver chemotherapeutic  
243   drugs to cancer cells<sup>62</sup>, and those on the order of tens of nanometers in size have been found  
244   to enter cells and eventually even cell nuclei.<sup>63,64</sup> Furthermore, Geiser et al. (2003) showed that  
245   inhaled spherical microparticles of Teflon were able to migrate into the surface lining layer of  
246   hamster alveoli, where interactions with lung cells could occur.<sup>65</sup> Many fluoropolymers are  
247   marketed in the form of suspensions with sub-micron fluoropolymer particle sizes (see, e.g.  
248   <https://www.teflon.com/en/products/dispersions>), thus, release of bioavailable fluoropolymer  
249   particles is plausible. Based on such emerging evidence from environmental and medical  
250   research on diverse macromolecules<sup>66</sup>, a blanket statement that polymers cannot enter cells is  
251   factually inaccurate.

252 It is recognized, however, that the global production of fluoropolymers (though not insignificant  
253 at 320 000 tons in 2018<sup>4</sup>, and increasing<sup>3</sup>) is relatively low in volume compared to global  
254 production of plastics (300 million tons in 2018<sup>67</sup>) and therefore nano-sized fluoropolymers may  
255 not make a large contribution to the total exposure to, and toxicity, of nano-plastics.  
256 Furthermore, the exposure and toxicity of nano-plastics is an area of ongoing research with  
257 many unknowns.<sup>68</sup>

258

## 259 **7. Persistence and disposal of fluoropolymers**

260 Fluoropolymers are extremely persistent<sup>42</sup>, which, in the same way as for other polymers, can  
261 lead to a wide array of issues, particularly with respect to disposal of fluoropolymer-containing  
262 wastes and products.<sup>69</sup> Current concern over microplastics present in the oceans provides an  
263 example of why manufacture of polymers likely to be released into the environment should  
264 ideally be curtailed<sup>70</sup>, or move to easily recyclable materials.<sup>71</sup> Hence, production of persistent  
265 polymers, such as the highly persistent fluoropolymers, should occur only in currently essential  
266 use categories.

267 At the industrial scale, recycling of clean PTFE waste or scraps generated during production is  
268 already happening, often by converting these into PTFE micropowder (so-called fluoroaditives)  
269 and then using them to reduce wear rate and friction.<sup>72</sup> This has the unintended consequence  
270 of spreading fluoropolymers into more uses, and complicating any efforts of controlling and  
271 reducing their losses from the technosphere. More recently, a pilot-scale industrial high-

272 temperature recycling process (vacuum pyrolysis) to regenerate gas-phase monomers from  
273 end-of-life industrial-scale fluoropolymer products has been established.<sup>73</sup>

274 On the other hand, the recycling of fluoropolymers in consumer products is not well established,  
275 as those fluoropolymers are typically contaminated by other substances and fillers, which makes  
276 recycling difficult.<sup>73,74</sup> Fluoropolymers applied to metal products (e.g., nonstick frying pans)  
277 might end up in metal recycling streams, leading to their uncontrolled breakdown in metal  
278 smelters at high temperatures.

279 Commercial bakeries regularly remove fluoropolymer coatings from their baking forms after 12-  
280 24 months of use either via burning or blasting, with unknown emissions of PFASs and  
281 fluoropolymer particles to air, water and soil, and then have the forms re-coated. In Sweden  
282 alone, for example, every year some 20 000 baking pans are 'recoated' with a total baking surface  
283 of 500 000 m<sup>2</sup>. Stripping the old coating is performed by either 'burning off' at 450 °C for 4-5 h to  
284 'break down' the coating followed by grit blasting or by water blasting at 1500 bar; it is unclear  
285 whether emissions are controlled.<sup>75</sup>

286 Landfilling of fluoropolymers leads to contamination of leachates with PFAS and can contribute  
287 to releases of plastics and microplastics. Even with an exceptional chemical and thermal stability,  
288 fluoropolymer particles will be disintegrated into microplastics by weathering and physical stress,  
289 which enables further dispersion and increased bioavailability.<sup>76,77</sup> Storage in abandoned mines  
290 and oil extraction fields is an option not routinely explored (except when court-ordered, see  
291 below), but is costly and logistically complicated.

292 The remaining option for the disposal of fluoropolymers is incineration; its effectiveness to  
293 destroy PFAS and the tendency for formation of fluorinated or mixed halogenated organic  
294 byproducts is not well understood<sup>78</sup>. Fluorinated compounds are more difficult to destroy than  
295 other organic compounds.

296 Tetrafluoromethane and perfluoroethane have been identified as very stable combustion  
297 byproducts from the incineration of fluorine-containing waste, but given the extra stability of  
298 perfluorinated radicals, larger molecules might also be formed as a result of incomplete  
299 combustion.<sup>78,79</sup> PTFE can produce PFCAs (including trifluoroacetic acid (TFA)) and other  
300 fluorinated compounds when heated above about 250 °C and up to 600 °C (relevant for  
301 uncontrolled burning).<sup>80-83</sup> Myers et al. (2014) identified multiple thermal decomposition  
302 products of polychlorotrifluoroethylene (PCTFE), a common fluoropolymer, including 29  
303 perhalogenated carboxylic acid congener classes and 21 chlorine/fluorine substituted polycyclic  
304 aromatic hydrocarbon congener classes.<sup>84</sup>

305 It is currently unclear whether typical municipal solid waste incinerators can safely destroy  
306 fluoropolymers without emissions of harmful PFAS and other problematic substances.

307 Combustion within an optimized waste incinerator (870 °C, 4 s residence time of 0.3% PTFE by  
308 weight), as opposed to the less strict 850 °C and 2 s required in the EU for municipal solid waste  
309 incinerators<sup>85</sup> yielded inconclusive results with respect to stack emissions of PFAS.<sup>86</sup> PFOA was  
310 regularly detected in the exhaust, but the study was marred by elevated blanks. The authors  
311 were only able to account for 56-78% of the fluorine mass balance during incineration, meaning  
312 that a wide variety of other PFAS could have been released.<sup>86</sup> In any case, municipal waste

313 incinerators can only tolerate limited amounts of fluoropolymers due to the corrosive nature of  
314 the hydrogen fluoride released during the fluoropolymers' thermal decomposition.<sup>42</sup>

315

316 **8. Can fluoropolymers be considered separately from the use of PFAS as processing**  
317 **aids?**

318 For current manufacturing processes, it has not been clearly demonstrated that those  
319 fluoropolymer products that are made using emulsion polymerization (in contrast to  
320 suspension polymerization) can be produced without the use and emissions of PFAS as  
321 processing aids. For example, after discovery of widespread PFAS contamination of the Cape  
322 Fear watershed resulting from the production of fluoropolymers, a "Zero" emission policy to  
323 water was mandated in North Carolina.<sup>11</sup> This includes the capture of PFAS-containing liquid  
324 processing waste, which is now moved out of the state for deep well injection, merely  
325 relocating the environmental concern. Emulsion polymerization processes with much reduced  
326 PFAS use,<sup>87</sup> or without the use of PFAS,<sup>41,88</sup> as processing aids have been developed, but a  
327 phase-out of all PFAS as fluoropolymer processing aids has not yet been implemented.

328

329 **9. Are fluoropolymers polymers of low or high concern?**

330 The concerns we present above suggest that there is no sufficient evidence to consider  
331 fluoropolymers as being of low concern for environmental and human health. The group of  
332 fluoropolymers is too diverse to warrant a blanket exemption from additional regulatory



333 review. Their extreme persistence and the emissions associated with their production, use, and  
334 disposal result in a high likelihood for human exposure as long as uses are not restricted.  
335 Concluding that some fluoropolymers are of low concern for environmental and human health  
336 can only be achieved by narrowly focusing on their use phase as was done by Henry et al  
337 (2018).<sup>2</sup>

338 Ideally, the assessment and management of fluoropolymers would consider the complete life  
339 cycle including associated emissions during production and disposal, as described above (see  
340 also Figure 1). The ECETOC CF4Polymers framework was an improvement over the OECD PLC  
341 criteria by introducing life cycle considerations in polymer risk assessment and it is  
342 recommended that these approaches are applied rather than focusing narrowly on the use  
343 phase. Monitoring emissions of harmful volatile and particulate PFAS at manufacturing and  
344 incineration sites is urgently needed. Furthermore, mapping of all industrial activities that  
345 produce, process and dispose/incinerate fluoropolymers would allow for targeted monitoring  
346 of potentially contaminated sites and protection of potentially exposed communities.

347 Further, there is no scientific basis to separate and subsequently remove fluoropolymers from  
348 discussions of other PFAS as a class or in terms of their impacts on human or environmental  
349 health. The conclusion that all fluoropolymers are of low concern, simply based on tests on  
350 limited finished products of four types of fluoropolymers,<sup>2</sup> ignores major emissions linked to  
351 their production, and large uncertainties regarding their safe end-of-life treatment.

352 In addition, there is only very limited information on the compositions, grades, etc. of the  
353 fluoropolymers on the market. Not all fluoropolymers meet the OECD PLC criteria, as suggested

354 by Henry et al. (2018) in the conclusions of their paper; for example, functionalized  
355 fluoropolymers do not meet the criteria (e.g. Nafion) due to the presence of reactive functional  
356 groups. It would anyway be impossible to verify if all fluoropolymer products were PLC or not  
357 with the information available in the public domain. If PLC is part of a regulatory framework,  
358 PLC assessment should be performed on a product-by-product basis because various grades  
359 and commercial products of fluoropolymers may or may not meet the PLC criteria. For example,  
360 a PTFE product made in China cannot be assumed to be equivalent to the PTFE products tested  
361 by Henry et al. (2018).<sup>2</sup> Our recommendation is to move toward the use of fluoropolymers in  
362 closed-loop mass flows in the technosphere and in limited essential-use categories, unless  
363 manufacturers and users can eliminate PFAS emissions from all parts of the life cycle of  
364 fluoropolymers.

365

## 366 **Acknowledgements**

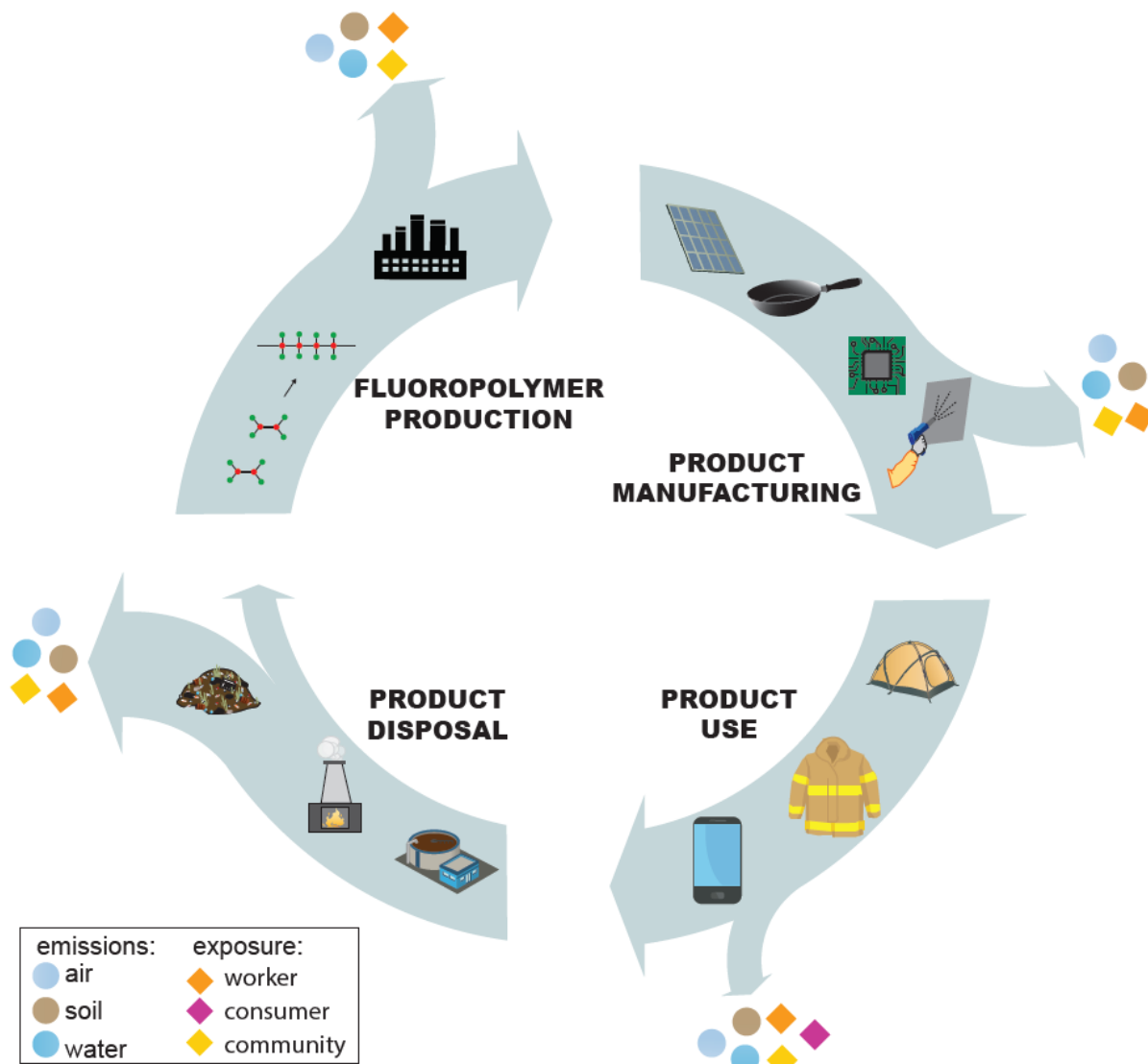
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378

379 **Figure 1: Conceptual diagram of the life cycle emission during fluoropolymer production, product**  
380 **manufacturing and disposal.**

381



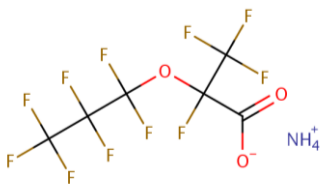
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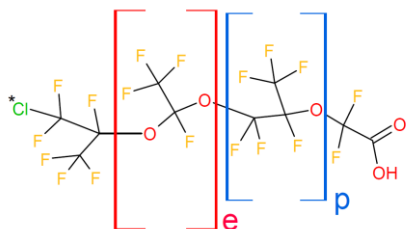
385

386 **Figure 2: Structures of replacement fluoropolymer processing aids detected in the environment**



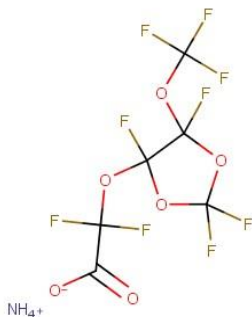
387

388 a) Ammonium salt of hexafluoropropylene oxide dimer acid (HFPO-DA, CAS 62037-80-3, or GenX)  
389 detected in the environments of North Carolina and the Netherlands.



390

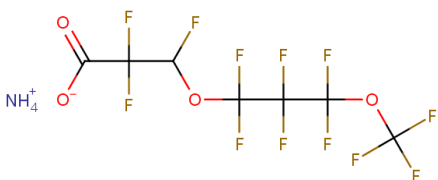
391 b) Functionalized PFPE reported in Wang et al. 2013 (CAS 329238-24-6) now observed in Bormida River  
392 (Italy) and New Jersey. Note: the e = ethyl group can range from 0 - 2 units and p = propyl group can  
393 range from 1 – 4 units with the ethyl group most likely being closest to the chlorine. Additionally, the  
394 chlorine can be on the terminal carbon as shown or on the C2 position as CF<sub>3</sub>CF(Cl)CF<sub>2</sub>-O.



395

396 c) Perfluoro{acetic acid, 2-[(5-methoxy-1,3-dioxolan-4-yl)oxy]}, ammonium salt (CAS No 1190931-27-1)  
397 (cC604) now observed in ground- and surface water in the Veneto region (Italy).

398 <https://echa.europa.eu/substance-information/-/substanceinfo/100.207.411>



399

400 d) Ammonium 4,8-dioxa-3H-perfluorononanoate (CAS 958445-44-8) (ADONA) detected in the Rhine  
401 River and serum samples.

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419 [\\_Korea\\_Taiwan\\_Philippines.html](https://www.chemsafetypro.com/Topics/Review/polymer_registration_in_EU_USA_China_Japan_Korea_Taiwan_Philippines.html) (accessed Apr 6, 2020).
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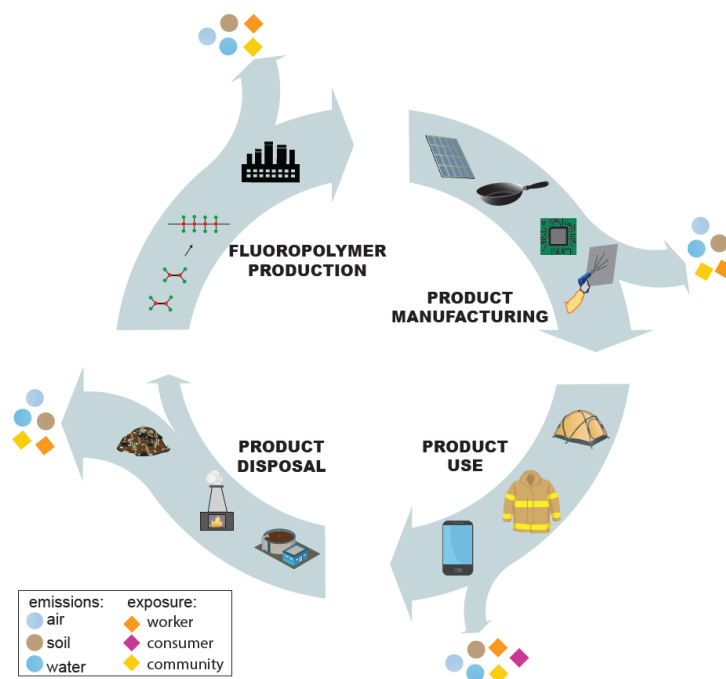
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## Graphical TOC

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