Fluoropolymers: The Safe Science That Society Needs

*Jaime Sales, Francisco Hernández, Deepak Kapoor and Marcel van den Noort**

Fluoropolymers are high value chemicals that provide a wide variety of properties in key industrial sectors. These chemicals are indispensable to guarantee the adequate functioning of modern society, with key contributions in safety, decarbonization, and high-tech development. Due to their chemical composition and structure, fluoropolymers match the definition of the PFAS group of substances. However, this definition was originally not intended for regulatory purposes. Indeed, this group of substances is currently under heavy pressure due to the fact that some other chemicals in the group have raised environmental concerns in the past. However, fluoropolymers show clearly differentiated properties from other PFAS, and the vast majority of these polymers have been identified as matching the definition of Polymer of Low Concern. Fluoropolymers are not expected to degrade during normal use or at their end of life, and the main concerns related to their manufacture are being successfully addressed by industry, with innovative developments in both safer designs and improvement of abatement techniques to control emissions.

I. Introduction

For several years, per-and polyfluoroalkyl substances (PFAS) have been on the radar of regulators, scientists, non-governmental organizations, and consumers globally, because some chemicals pertaining to this very wide group of substances have been found to be persistent, bioaccumulative, and toxic to human health and the environment. For some of these substances, this concern is justified and their (eco)toxic effects are well known. This is the case, for example, with perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), for which regulatory controls have been implemented in major economic regions where they were used extensively. Regulators in these countries are now concerned about other PFAS substances where data on (eco) toxicity is not available and hence they could pose a potential risk in the future specially because they are likely to be persistent owing to strong C-F bond. However, the broad group of PFAS also includes groups of substances - which exhibit clearly differentiated properties compared to other substances in the PFAS group, particularly related to their expected impact on humans and the environment, degradation potential to PFAS of concern and specific applications of use. One of such unique group is fluoropolymers. This paper highlights the differences that can be established between fluoropolymers and other substances in the PFAS group and provides arguments to justify that these chemicals should be regulated separately from other PFAS.

Fluoropolymers are high molecular weight substances structurally characterised by having fluorine atoms directly attached to their carbon-only backbone. This differentiates fluoropolymers from other substances typically included in the PFAS group of chemicals. In fact, they can also be further differentiated from other polymeric fluorinated substances, such as side-chain fluorinated polymers (SCFPs) or perfluoropolyethers (PFPEs).

The main fluoropolymers meet criteria to be identified as Polymers of Low Concern (PLC) as developed by the Organisation for Economic Co-operation and Development (OECD). Existing scientific data demonstrates that, because of their unique set of properties, such as negligible solubility in water or high molecular weight, fluoropolymers cannot enter

* Jaime Sales, Regulatory Advisors Chemservice Iberia S.L., Castellón, Spain. Francisco Hernández, Regulatory Advisors Chemservice Iberia S.L., Castellón, Spain. Deepak Kapoor, Gujarat Fluorochemicals GmbH, Regus Centre Watermark, Hamburg, Germany. Marcel van den Noort, Gujarat Fluorochemicals GmbH, Regus Centre Watermark, Hamburg, Germany. For correspondence <[redacted]@chemservice-group.com>.

or accumulate in the human tissue, and they cannot degrade into other PFAS under intended conditions of use or under ambient environmental conditions. Therefore, it is considered that fluoropolymers do not pose a significant risk to water quality, human health, or the environment. Finally, potential indirect situations that may generate concerns related to PFAS emissions, such as the need to use fluorinated polymerisation aids in the fluoropolymer manufacturing process, are being addressed by industry, with significant progress made over the last years. Furthermore, the End-of-Life (EOL) phases of applications related to fluoropolymers are not expected to be of concern.

However, since fluoropolymers meet the OECD definition of PFAS, they are included in the scope of the restriction proposal that 5 Competent Authorities from Member States of the European Economic Area have announced on the broad PFAS group of chemicals under the REACH Regulation[1]. Therefore, fluoropolymers could face market restrictions in Europe if their differentiated properties are not clearly highlighted in the restriction proposal. This could even lead to a ban on the uses of these high value materials in different applications in which they are used.

This paper argues for an exemption of the Fluoropolymer group from the PFAS restriction proposal.

II. Societal Importance of Fluoropolymer Applications

Fluoropolymers are used in a wide variety of highly critical applications due to their valuable properties, mainly by industrial actors.[2] In the case that the use of fluoropolymers would be banned in Europe, a number of critical sectors would be significantly impacted, which could result in severe damage to the European society. The list below covers just a selection of examples of industries that could be damaged because of this.

- Renewable Energy: fluoropolymers are key components in solar panels and wind turbines, where they protect against weather impacts of equipment exposed to e.g., rain and environmental contaminants. In photovoltaic cells, fluoropolymers improve electrical insulation. Furthermore, these materials are critical and absolutely necessary for optimal performance of lithium-ion batteries and hydrogen fuel cells. Without fluoropolymers, these devices will not work efficiently, and the goals of the European Green Deal would be seriously compromised.
- **Semiconductors**: fluoropolymers provide properties that are essential in this use, such as resistance to harsh chemicals that need to be used in the manufacturing process while providing an environment completely free of impurities. No fluoropolymers available will mean that the semiconductor industry will not be able to produce the high-tech microchips that allow for the development of modern (and reduced in size yet powerful) devices such as mobile phones, laptops and many other high-tech equipment.
- Chemical process industry: due to their unmatched properties in terms of resistance to chemical attack and optimum performance under wide variations of temperature, fluoropolymers are the only available set of products on the market that allow for adequate performance of many chemical processes. While other materials could be used for handling chemical streams, these would need continued maintenance and replacement and what is worse, they would significantly increase the risk of failure and accidents, leading to higher probability of operators and the environment being unexpectedly exposed to highly hazardous chemicals. Fluoropolymers can be found in all kinds of tubing and industrial equipment, as well as joints and gaskets to secure operation and containment of chemicals.
- Transport: fluoropolymers contribute to both fuel efficiency (as key components in combustion engines) and safety, playing a key role in systems such as brakes in cars or wing flaps in aircrafts. They are also the best option available (due to their high resistance but also high flexibility) to protect electrical cables in aircrafts, where high reliability of such cables, which can be exposed to thermal as well as chemical pressure, is fundamental.
- Food and water treatment: wherever high purity is required, fluoropolymers play an irreplaceable role. These materials are present in water filtration systems (which avoids the need to use chem-

1 Regulation (EC) No 1907/2006

2 Fluro Council, 'Understanding FluoroTechnology' (2017) <https://fischerpaperproducts.com/wp-content/uploads/2017/02/Understanding-Fluorotechnology-FluoroCouncil.pdf> accessed 24 October 2022.

icals for water treatment) and also in food processing systems to guarantee adequate sanitary conditions and avoid contamination which could otherwise reach consumers.

– Pharmaceutical and medical devices: medical implants that are intended to be used in the human body (catheters, implants) due to their biological compatibility and inertness. Certainly, materials that are used for this purpose are not toxic for human health and, due to their high durability, can last for many years in the body without replacement. Furthermore, the production of medicines and vaccines by the pharma industry require as well ultra purity conditions which can only be achieved with equipment based on fluoropolymer materials.

III. Fluoropolymers Inside the Broad PFAS Group

PFAS are a group of 4,730 different highly fluorinated synthetic (man-made) substances[3], both polymeric and non-polymeric, although other sources increase the number to approximately 9,000 chemicals.[4] They are grouped together in accordance with a common definition based on chemical structure[5]: "*PFASs are defined as fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it), i.e., with a few noted exceptions, any chemical with at least a perfluorinated methyl group (–CF3) or a perfluorinated methylene group (–CF2–) is a PFAS.*"

It should be noted that such definition was originally not intended to be used for regulatory purposes.[6] This has been highlighted recently in a publication by an independent panel of experts on the topic, which generally concluded that all PFAS should not be grouped together for the purpose of assessing human health risks, and that the definition of appropriate subgroups can only be defined on a case-by-case manner.[7]

Due to the large number of chemicals pertaining to this group, and the wide variability of composition and properties, PFAS can be divided in different families. A summary of the structure of the PFAS group is displayed in **Figure 1**.[8]

As seen in **Figure 1**, fluoropolymers are part of the PFAS group by definition. However, they are different to other PFAS due to their polymeric nature. A polymer is defined as a molecule of high relative molecular mass (macromolecule), the structure of which essentially comprises the multiple repetitions of units derived from molecules of low relative molecular mass, known as monomers.[9] In the case of fluoropolymers, this macromolecule is a long chain (backbone) of thousands of connected carbon atoms to which fluorine atoms are bound.[10] For this reason, this family of synthetic polymers can be easily differentiated from the non-polymeric PFAS, which are also based on chains of carbon atoms, but which are much shorter than those of polymers (chain length between 2 and 13 carbon atoms).

According to the bibliography, out of the 4,730 substances included in the PFAS category,[11] only 256 are commercially relevant.[12] In the case of fluoropolymers, only 38 substances are currently available on the market, out of the 267 compounds that are currently identified. This means that commercial fluoropolymers only represent 0.8% of the PFAS universe, but they represent 14.8% of the PFAS with commercial relevance. This is a good illustration of how important fluoropolymers are in modern society, due to the unique properties of these materials and their superior performance in many applications.

3 OECD, 'Toward a new comprehensive global database of per- and polyfluoroalkyl substances (PFASs)' (2018) Series on Risk Management, 39.

4 The National Institute for Occupational Safety and Health (NIOSH), 'Per- and polyfluoroalkyl substances (PFAS)' (2022) <https://www.cdc.gov/niosh/topics/pfas/default.html> accessed 24 October 2022.

5 OECD, 'Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance' (2021) Series on Risk Management, 61.

6 Ibid.

7 J k Anderson et al, 'Grouping of PFAS for human health risk assessment: Findings from an independent panel of experts' (2022) Regulatory Toxicology and Phamacology, 134.

8 Interstate Technology Regulatory Council (ITRC), 'Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances' (2020) <https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_Naming_Conventions_April2020.pdf> accessed 24 October 2022.

9 IUPAC, 'What are polymers? International Union of Pure and Applied Chemistry' (2022) <https://iupac.org/polymer-edu/what-are-polymers/> accessed 24 July 2022.

10 Plastics Europe, 'Fluoropolymers vs. Side chain fluorinated polymers' (2022) <https://fluoropolymers.plasticseurope.org/application/files/3516/3913/1778/Fluorpolymers_vs._side_chain_fluorinated_polymers_final.pdf> accessed 24 July 2022.

11 (n 3).

12 R C Buck et al, 'Identification and classification of commercially relevant per- and poly-fluoroalkyl substances (PFAS)' (2021) Integrated Environmental Assessment and Management 17, 1045–1055.

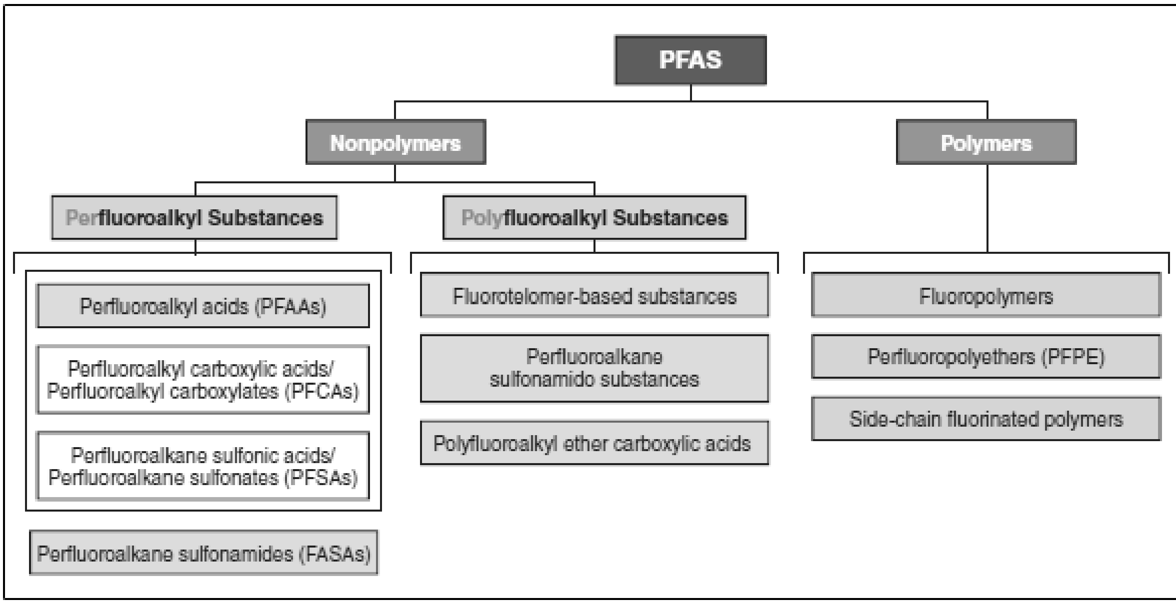

Figure 1: Structure of families in the PFAS Group

IV. Fluoropolymers are Non-Toxic, Polymers of Low Concern

Existing scientific data demonstrates that, because of their unique characteristics such as the negligible solubility in water or the high molecular weight, fluoropolymers cannot enter or accumulate in the human bloodstream. Therefore, fluoropolymers are do not pose a significant risk to human health, or the environment.[13] This allows to conclude that fluoropolymers meet the criteria to be identified as PLC. While the PLC criteria are not completely agreed worldwide, basic consensus exists around the following:[14]

- High molecular weight, based on the Number-average molecular weight (Mn): an Mn of ≥1,000 Da is a generally accepted Mn range for a PLC.
- Content of low molecular weight, oligomeric species (no common levels accorded among global regulations).
- Presence (or absence) of specific reactive functional groups (RFGs) in the polymer: these are functional groups that are known to be associated with toxicity of polymers and include cationic species that are known to result in aquatic environmental toxicity.
- Solubility (in water and other solvents): polymers with water solubilities <10 mg/L showed generally low health concern.
- Other criteria: stability of the polymer, chemical class (or polymer class), residual monomer content and human health hazard classification.

In order to establish if fluoropolymers meet these conditions, research was originally conducted on a set of 4 specific polymers: polytetrafluoroethylene (PTFE), ethylene- tetrafluoroethylene copolymer (ETFE), tetrafluoroethylene-hexafluoropropylene copolymer (FEP), and tetrafluoroethylene-perfluoroalkyl trifluorovinyl ethers copolymer (PFA). The evaluation of these fluoropolymers[15] shows that they satisfy the widely accepted assessment criteria to be considered PLCs. All of them are high molecular weight polymers, stable against hydrolysis, light, oxidation, and biodegradation, and thermally stable in the range of 150 °C to 260 °C.

13 B J Henry et al, 'A Critical Review of the Application of Polymer of Low Concern and Regulatory Criteria to Fluoropolymers' (2018) 14 Integrated Environmental Assessment and Management 3, 316–334. S H Korzeniowski et al, 'Critical Review of the Application of Polymer of Low Concern Regulatory Criteria to Fluoropolymers II: Fluoroplastics and Fluoroelastomers' (2022) Integrated Environmental Assessment and Management.

14 OECD, 'Data analysis of the identification of correlations between polymer characteristics and potential for health or ecotoxicological concern' (2009) <http://www.oecd.org/chemicalsafety/risk-assessment/42081261.pdf> accessed 24 July 2022; Deloitte, 'Technical assistance related to the review of REACH with regard to the registration requirements on polymers' (2015) Final report prepared for the European Commission (DG ENV), in collaboration with PIEP.

15 (n 13).

Also, they are practically or completely insoluble in water and not soluble in octanol. As solubility in octanol is predictive of lipid solubility, it can be expected that fluoropolymers do not dissolve in cell membrane lipids to gain access to cellular contents. Because these fluoropolymers cannot enter the cells, they are not capable of bioaccumulation or bioconcentration in aquatic life.

More recent research has expanded these conclusions to cover 14 additional fluoropolymers.[16] The new data confirms the same conclusions as originally established by Henry et al. in 2018, for the original set of 4 fluoropolymers; it is confirmed that all the fluoropolymers evaluated (covering approximately 96% of the global fluoropolymer market) fulfill the PLC criteria, and can therefore be expected to be negligibly soluble, not mobile, not bioavailable, not bioaccumulative, and not toxic.

V. Fluoropolymers are Different From Other Polymeric PFAS

As discussed in **Section II**, fluoropolymers can be clearly differentiated from short-chain or long-chain non-polymeric PFAS. But fluoropolymers are also different from the other families of polymeric PFAS, such as SCFPs or PFPEs, on the basis of their nature, structure, uses, and applications, as well as from the point of view of safety and expected environmental impacts.

Attending to the structure of the macromolecules, the polymeric PFAS can be grouped in the following three main categories:[17]

- Fluoropolymers: have a carbon polymer backbone with fluorine atoms directly attached to carbon atoms in the backbone.[18]
- PFPEs: have a polyether polymer backbone, in which repeating monomer contains a carbon-oxygen bond, with fluorine atoms directly attached to carbon atoms in the backbone.
- SCFPs: have a carbon polymer backbone with fluorinated side chains directly attached to carbon atoms in the backbone. In this case, fluorine atoms are not directly attached to carbon atoms in the backbone. In the final structure, the fluorinated side chains are attached to the polymer backbone by a spacer moiety and a linking group.[19]

The different groups of polymeric PFAS based on their structure are displayed in **Figure 2** (Wahlström et al., 2021).

These differences in the structure of the polymeric PFAS have consequences in their properties. Fluoropolymers are solid materials known for exhibiting material properties (i.e., intrinsic to the material), whereas SCFPs, marketed as liquids, greases, or dispersions in water, have surface properties, which means that they act in direct contact with products to which they are applied. This fact has implications in the downstream uses of these materials. For example, fluoropolymers are not used in firefighting foams, which is a classical application of SCFPs. In general, while fluoropolymers are used mainly in industrial applications, such as chemical processing industries, renewable energy, telecommunications, electronics and semiconductors, automotive and aerospace, food and water processing, architecture and building, and medical devices,[20] SCFPs are typically used in consumer applications, such as surface protectors to provide water, oil, and stain repellence to textiles, apparel, leather, carpets, nonwovens, and paper, and soil release properties.[21] In relation to PFPEs, while these are mainly used as lubricants in specific industrial sectors, certain consumer applications related to surface protection are also relevant.[22]

Finally, fluoropolymers are substantially different from the other polymeric PFAS in terms of potential emissions due to degradation into small PFAS molecules during intended use or under environmental conditions and, for this reason, they have no environmental impact. Fluoropolymers have a high molecular weight, little to no water solubility and volatility, therefore they are not expected to degrade to low-

16 (n 12).

17 European Commission, 'Scientific and technical support for the development of criteria to identify and group polymers for Registration/Evaluation under REACH and their impact assessment' (2020).

18 (n 13).

19 H Fiedler, 'A critical review of a recommended analytical and classification approach for organic fluorinated compounds with an emphasis on per- and polyfluoroalkyl substances' (2020) 17 Integrated Environmental Assessment and Management 2, 331–351.

20 J Glüge J, 'An overview of the uses of per- and polyfluoroalkyl substances (PFAS)' (2020) Environmental Science: Processes & Impacts 22, 2345; S Banerjee, 'Poly(fluoroacrylate)s with tunable surface hydrophobicity via radical copolymerization of 2,2,2-trifluoroethyl α-fluoroacrylate and 2-(trifluoromethyl)acrylic acid' (2017) Polymer Chemistry 8, 1978.

21 (n 20) Glüge et al; (n 2).

22 (n 19).

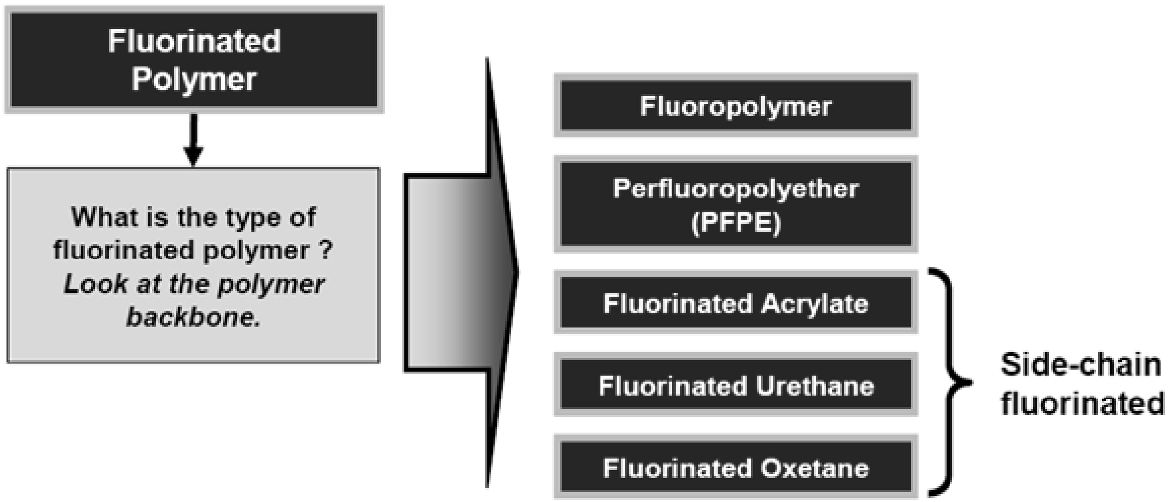

Figure 2: Types of Polymeric PFAS Based on Their Structure

er molecular weight PFAS.[23] Also, they are not expected to lead to the formation of long-chain PFAS as a result of degradation.[24] PFPEs exhibit a similar behaviour to fluoropolymers,[25] because the repeating units of the PFPEs contain only 2 or 3 perfluorinated carbon atoms per oxygen atom, and their degradation cannot lead to the formation of long-chain PFAS.[26]

However, the linking group in the structure of the SCFPs can be susceptible to cleavage, depending on the structure of each material, resulting in loss of the fluoroalkyl side chain. Thus, SCFPs can ultimately be a source of perfluoroalkyl acids (PFAAs), such as PFOA, PFOS, perfluorobutanoic acid (PFBA), perfluorohexane sulfonic acid (PFHxS), or perfluorohexane carboxylic acid (PFHxA), unless there is stability data to prove otherwise. This means that, under environmental conditions, SCFPs can degrade to these non-polymer PFAS, which are well known due to their negative effects on the environment.

VI. Use of PFAS as Polymerisation Aids in the Production of Fluoropolymers

The main concerns that have been typically flagged in relation to fluoropolymers are not based on these materials as such, but on the use of other PFAS substances in the manufacturing process of fluoropolymers. Under certain conditions, the use of short-chain PFAS as polymerisation aids (surfactants) is necessary to achieve the final fluoropolymer substance. This may result in emissions of PFAS from the fluoropolymer manufacturing process. In addition, residuals of these fluorinated surfactants may be carried over with the final fluoropolymer substance down the supply chain, which may also result in additional PFAS emissions from fluoropolymer products during the life cycle. The production process can also involve the generation of unintended fluorinated oligomers or lower molecule polymers during the process.

All the above items of concern have been raised by researchers (Lohmann et al., 2020) and regulators. The fluoropolymer industry is committed to addressing these issues, and improvements in the fluoropolymer manufacturing process continue to be investigated. Furthermore, the fluoropolymer industry in Europe, via the Fluoropolymer Products Group (FPG) of Plastics Europe, recently commissioned a Regulatory Management Option Analysis (RMOA) on fluoropolymers. The objective of the RMOA was to evaluate the possible Regulatory Management Options (RMOs) that could be applicable to fluoropolymers, and to identify the most appropriate one in terms of

23 Ibid; The Danish Environment Protection Agency, 'Survey of PFOS, PFOA and other perfluoroalkyl and polyfluoroalkyl substances' (2013) Environmental Project No 1475.

24 (n 17).

25 (n 17); (n 19).

26 (n 12).

different parameters, such as effectiveness and proportionality. As a conclusion of this RMOA (Plastics Europe, 2022),[27] the fluoropolymer industry in Europe has established a commitment to make efforts to address the existing concerns related to the use of fluorinated polymerisation aids (FPAs) in the manufacture of fluoropolymers, and to work on minimizing emissions of low carbon chain fluorinated by-products.

Several fluoropolymer manufacturers have recently announced important achievements in the development of manufacturing processes that do not require the use of FPAs.[28] These achievements, which result in technically equivalent fluoropolymer grades with no presence of unintended fluorinated by-products, are expected to have significant impact in future trends of fluoropolymer manufacture, as they should lead towards a clear reduction of the use of such fluorinated surfactants. In this regard, it is worth mentioning that, according to IHS and Chemical Economic Handbook (CEH) reports, it is estimated that 55.2% of fluoropolymer production does not require the use of FPAs.[29] The global production of fluoropolymers is estimated at approximately 320,000 tonnes per year. **Table 1** shows information from sources related to total volume of the main substances in the fluoropolymer family, according to the sources.

With the full implementation of these new achievements as announced by industry, it is expected that close to 83% of the global production will not require the use of short-chain PFAS. It is to be noted that the three main fluoropolymers by volume (PTFE, PVDF and FKM) will shortly be manufactured fully without the use of FPAs, reaching only with this three fluoropolymers almost 80% of global volume (and this number is expected to grow, with expected increased volumes for some of those polymers, such as PVDF in the electric vehicle industry). Still, industry continues to make efforts on research and development to completely remove the use of fluorinated surfactants from the manufacture of fluoropolymers. While it is difficult to anticipate a date when 100% production will be possible without the use of FPAs, key industrial players expect that within 10 years they will be at or very close to that objective.

In parallel to this, it is worth highlighting that industry has also made significant progress in the development of abatement techniques that currently allow for close to or even above 99% recovery of any PFAS emissions that could be related to the manufacturing process of fluoropolymer.[30] Coupled with the continued efforts to remove FPAs from the manufacturing process, it is expected that the production (and continued use) of fluoropolymers will be performed under conditions that will not generate any significant risks to human health or the environment in terms of exposure to PFAS.

VII. Fluoropolymers Do Not Generate Significant Concerns During End-of-Life

An additional reason of concern to regulators and researchers related to fluoropolymers is the EOL stage of products manufactured with these polymers, due to uncertainties in the fate of these persistent polymers if landfilled, or to potential generation of additional PFAS during incineration.

It is relevant to note that, precisely because fluoropolymers are used in specific industrial applications, the waste phase for many of those sectors of use is already significantly regulated and therefore waste containing fluoropolymers will be adequately managed, in many cases via specific legislation (e.g., electronics). In addition to this, it needs to be taken into account that fluoropolymers have a very long-life span in their applications of use (in many cases going above 30 years). This means that the rate of generation of fluoropolymer waste is significantly lower compared to other polymers (plastics). Indeed, based on recent studies that have evaluated available

27 Plastics Europe, 'Regulatory Management Option Analysis for Fluoropolymers' (2022) <https://fluoropolymers.plasticseurope.org/index.php/fluoropolymers/irreplaceable-uses-1/reports-policy-documents/rmoa> accessed July 24 2022.

28 Chemours, 'Chemours Announces Process Innovation with New Viton™ Fluoroelastomers Advanced Polymer Architecture (APA) Offering' (2022) <https://www.chemours.com/en/news-media-center/all-news/press-releases/2022/chemours-announces-process-innovation-with-new-viton-fluoroelastomers-advanced-polymer-architecture> accessed 24 August 2022; Solvay, 'Producing new fluoropolymers without fluorosurfactants' (2022) <https://www.solvay.com/en/article/eliminating-pfas> accessed August 24 2022; GFL, 'Company Announcement' 2022 <https://www.gfl.co.in/upload/pages/ebce5fed9030753d0ee651bf1f48d0a0.pdf> accessed August 24 2022.

29 IHS Markit, 'Chemical Economics Handbook' (2016) <https://ihsmarkit.com/products/fluoropolymers-chemical-economics-handbook.html> accessed 24 October 2024.

30 R Dams and K Hintzer, 'Industrial Aspects of Fluorinated Oligomers and Polymers, in Fluorinated Polymers' (2016) Polymer Chemistry Series Volume 2: Applications, 1-31; (n 28) Chemours.

Global production of fluoropolymers and use of FPAs.

Fluoropolymers	Volume (tonnes)	% of total volume	Use of FPAs	% volume that does not require the use of FPAs	% volume that will not require the use of FPAs
PTFE Total	169,759	53%			
PTFE Suspension	84,879.5	26.5%	N	26.5%	26.5%
PTFE Emulsion	84,879.5	26.5%	Y		26.5%
PVDF (Homopolymer + Copolymer)	51,248	16%	N	16%	16%
FKM	35,000	10.9%			
FKM Copolymer	25,000	7.8%	N	7.8%	7.8%
FKM Terpolymer	10,000	3.1%	Y/N	1.6%	3.1%
FEP	32,030	10%	Y		
PVF	6,406	2%	Y		
PFA	3,203	1%	Y		
ETFE	3,203	1%	Y		
THV	800	0.3%	Y		
ECTFE (Copolymer + Terpolymer)	2,200	0.3%	N	0.3%	0.3%
PCTFE	8,600	2.7%	N	2.7%	2.7%
Others	7,851	2.5%			
TOTAL	320,300			54.8%	82.9%

data from 2020,[31] it is anticipated that less than 0.01% by weight of fluoropolymers entered relevant waste streams in Europe. This is significantly lower to other plastics that are estimated at about 4.8%. In that year, the majority of fluoropolymers waste (83.5%) was either incinerated or thermally destructed. About 13% of the waste was landfilled, in an operation that is expected to result in no significant environmental concern.

Pilot studies of the most common form of EOL destruction, which is municipal incineration, of the most common fluoropolymer, which is PTFE, found that the combustion converted the fluorine into controllable hydrogen fluoride gas and that of the 31 PFAS species studied, no fluorine containing products of incomplete combustion were produced above background levels.[32]

31 Conversio, 'Fluoropolymer waste in Europe 2020 – End-of-life (EOL) analysis of fluoropolymer applications, products and associated waste streams' (2022).

32 K Aleksandrov, 'Waste incineration of Polytetrafluoroethylene (PTFE) to evaluate potential formation of per- and Poly-Fluorinated Alkyl Substances (PFAS) in flue gas' (2019) Chemosphere 226.

Related to the incineration, in 2021 the National Institute for Public Health and the Environment of the Netherlands carried out a literature study to investigate presence of PFAS in waste incinerator flue gases.[33] It was investigated to what extent and under what conditions PFAS, including fluoropolymers, are thermally degraded and what kind of incineration by-products are formed. In this research, PTFE was found to be the most stable fluorine-containing polymer. For PTFE, it was concluded that complete thermal decomposition is achieved at a temperature of about 800°C. It was therefore assumed that other fluorine-containing polymers also thermally decompose completely at a temperature of 800°C. Temperatures at the pyrolysis front and the combustion front in the waste-burning bed range from 900 to 1100°C,[34] which is well above the temperature of 800°C at which the complete thermal decomposition of PTFE is achieved.

Landfills that receive fluoropolymers containing wastes also effectively contain any fluorinated compounds that might leach from the fluoropolymer waste through their leachate collection systems. The European landfill directive defines the different categories of waste (municipal waste, hazardous waste, non-hazardous waste, and inert waste), and it applies to all landfills, defined as waste disposal sites for the deposit of waste onto or into land. Typically, fluoropolymer waste is chemically inert. Therefore, fluoropolymers disposed in landfills are not expected to pose any threat to human health and environment.

For certain applications like non-stick frying pans, industry is working on suitable labelling for proper collection and recycling of used pans.

VIII. Fluoropolymers Are Used in High Value Industrial Applications

Fluoropolymers are extremely stable, solid specialty materials that have unique physicochemical properties which render them specialty plastics that are virtually chemically inert, non-wetting, non-stick, and highly resistant to temperature variability, fire, and weather, and exhibit low flammability. They also display features such as low coefficient of friction, dielectric strength, and flexibility. The exceptionally strength of the carbon-fluoride bond in fluoropolymers generates these high value properties.[35]

These properties, and particularly the joint combination of all of them in single products, make them irreplaceable in many applications, and it is commonly accepted that their unique set of properties cannot be matched by alternative materials, particularly in the wide range of operability they offer. In fact, fluoropolymers are frequently the high-cost option in many industries, being the material of choice only when other products are known to fail to provide the required combination of properties for the desired application.

The industrial sectors in which fluoropolymers are typically used are chemical processing industries, transport (e.g., automotive, aerospace), electronics (semiconductors, data transmission cables, electrical cables), food and water processing, pharmaceutical, medical devices, or construction.[36] In most of these applications, fluoropolymers are used when the material of choice needs to withstand very harsh conditions in relation to e.g., chemical environment, very high or very low temperatures (sometimes involving wide temperature variations), usually combined with other required properties such as high flexibility, barrier properties, biocompatibility, electric properties, or flame retardancy, to name a few.

Frequently the value that fluoropolymers provide to these applications are strongly related to critical areas such as:

– Safety of human health or the environment, providing safe equipment required to handle harsh chemicals in many industries thus avoiding releases of hazardous materials (chemical industries, food processing, pharmaceuticals), or providing protection to a wide range of systems (data transmission, electric cables in automobiles or aircrafts, protecting passengers from failure events.
– Clean water, providing efficient filtration systems for water treatment and replacing outdated and environmentally aggressive processes.
– Green energy production, playing a key role in the efficient development of lithium-ion batteries or hydrogen fuel cells.

33 Rijksinstituut voor Volksgezondheid en Milieu, 'Per- and polyfluorinated substances in waste incinerator flue gases' (2021).

34 A Asthana et al, 'A 2-D mathematical model of on-grate municipal solid waste combustion' (2006) Sohn International Symposium Advanced Processing of Metals and Materials; A Asthana et al, 'A 2-D mathematical model of on-grate municipal solid waste combustion' (2006) Sohn International Symposium Advanced Processing of Metals and Materials.

35 (n 20).

36 (n 2).

– Semiconductors, where the use of fluoropolymers is irreplaceable for the purpose of ensuring the technology that is currently required to produce modern reduced electronic devices.

It is worth noting that in many cases, fluoropolymers were the innovative solution that was introduced to solve previous issues in terms of safety or performance. For example, fluoropolymer-based gaskets were implemented in the chlor/alkali process years ago, and they are still considered the Best Available Technology to replace asbestos gaskets due to obvious health concerns related to carcinogenicity potential of this material).[37] Furthermore, it is relevant to highlight that in some applications, products could still be manufactured without fluoropolymers, but not at the level of technological development that modern society demands. This is the case of semiconductors, which could indeed be manufactured if fluoropolymers were not available, but under technical conditions dating back many years, impacting for example on the size of microchips. This would make it factually impossible to produce modern gadgets (e.g., laptops, mobile phones) at sizes that are typical in modern society. In summary, in the absence of fluoropolymers, many EU industrial sectors would face a technological leap backwards of 50+ years, which would force Europe to lose its technological independence in front of other regions.

According to the bibliography, out of the 4,730 substances included in the PFAS category,[38] only 256 are commercially relevant.[39] In the case of fluoropolymers, only 38 substances are currently available on the market, out of the 267 compounds that are currently identified. This means that commercial fluoropolymers only represent 0.8% of the PFAS universe, but they represent 14.8% of the PFAS with commercial relevance. This is a good illustration of how important fluoropolymers are in modern society, due to the unique properties of these materials and their superior performance in many applications.

IX. Conclusions

Fluoropolymers are part of the PFAS group by OECD definition. For this reason, fluoropolymers are included in the scope of the restriction proposal that is being developed in the European Economic Area. However, because of their different chemical structure and properties, they need to be considered as a separate family within the broad PFAS group, clearly distinct not only from the non-polymeric PFAS, but also from the other polymeric PFAS. These differences are relevant not only in terms of grouping but more importantly also in relation to the risk for human health and the environment that will be derived from their manufacture and use.

The main differences between fluoropolymers and the other members of the large PFAS group of chemicals are the following:

– Structural differences, which render them a unique and clearly differentiated family of chemicals within the broad PFAS group, both from non-polymeric as well as from other polymeric PFAS.
– Safety and environmental considerations, since they meet the PLC conditions, due to their high molecular weight and negligible solubility in different fluids, and are thus not toxic, not bioavailable, not bioaccumulative, not mobile, and have insignificant human health or environmental impacts.
– Limited expected potential to degrade into small PFAS molecules during the intended use or under ambient conditions in the natural environment.
– Unique combination of properties, frequently related to the enhancement of safety of workers, population and the environment, as well as to the development of green energy solutions and high technological applications. This makes fluoropolymers extremely valuable and irreplaceable in extremely demanding uses in a wide variety of industrial sectors.

In parallel, industry has placed significant efforts to address the concerns that have been raised on fluoropolymers, related to the use of other PFAS as polymerisation aids in the manufacturing process that may result in emissions through the life cycle. Relevant achievements on this topic have been announced over the last months from different suppliers, as well as on the improvement of abatement techniques to control emissions.

37 Joint Research Centre, 'Best Available Techniques (BAT) Reference Document for the Production of Chlor-alkali' (2014) <https://publications.jrc.ec.europa.eu/repository/handle/JRC91156> accessed 24 August 2022.

38 (n 3).

39 (n 12).

The value that fluoropolymers provide to downstream applications is strongly related to critical areas such as:

- Safety of human health or the environment, providing safe equipment required to handle harsh chemicals in many industries thus avoiding releases of hazardous materials (chemical industries, food processing, pharmaceuticals), or providing protection to a wide range of systems (data transmission, electric cables in automobiles or aircrafts, protecting passengers from failure events.
- Clean water, providing efficient filtration systems for water treatment and replacing outdated and environmentally aggressive processes.
- Green energy production, playing a key role in the efficient development of lithium-ion batteries or hydrogen fuel cells.
- Semiconductors, where the use of fluoropolymers is irreplaceable for the purpose of ensuring the technology that is currently required to produce modern reduced electronic devices.

Based on all the data available, including recent positions expressed by different experts on the topic, it appears evident that fluoropolymers should not be grouped with other PFAS for risk assessment or regulatory purposes. If fluoropolymers are to be included in the upcoming PFAS restriction under the REACH Regulation, the most reasonable and proportionate decision would be to include a broad derogation to ensure continued use of these highly valuable, PLC materials. Such derogation could be conditioned to the continued replacement of fluorinated polymerization aids from the manufacturing process of fluoropolymers, which is ultimately the only reason for concern that could be justified for these chemicals, and not the intrinsic properties of fluoropolymers.