What Do We Know about PFAS? Issues, Challenges, Limitations, Regulations & Alternatives

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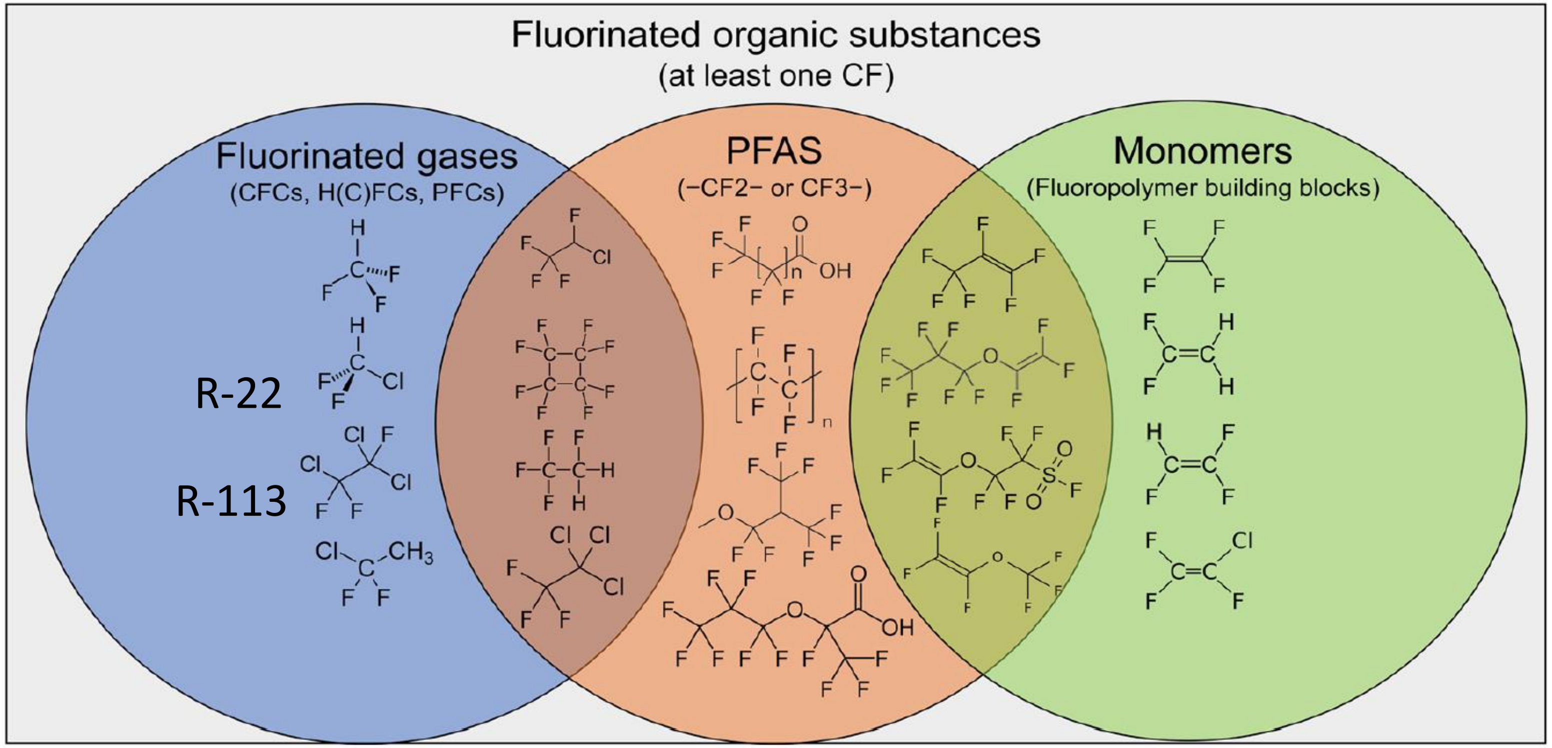
SFB 1349 Fluor-Spezifische Wechselwirkungen

Freie Universtität Berlin, April, 7th, 2025

Per- and Polyfluoroalkyl Substances (PFASs)

> 14,000 PFAS

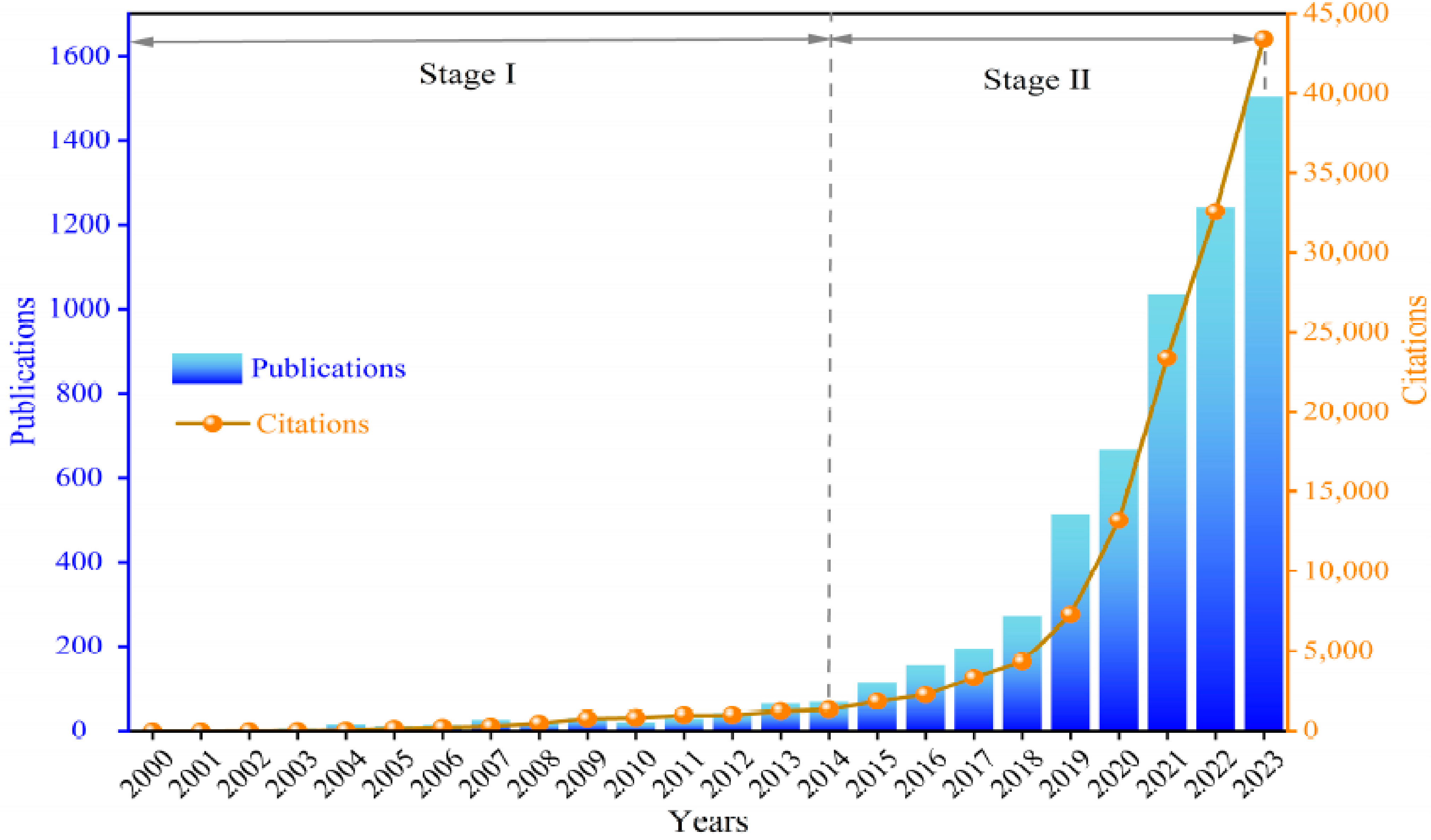
OECD (2021 version) definition of PFAS: *''PFASs (per- and polyfluoroalkyl substances) are defined as fluorinated substances that contain at least* ***a perfluorinated methyl group (–CF_3) or a perfluorinated methylene group (–CF_2–)*** *(without any H/Cl/Br/I atom attached to it).*



Organisation for Economic Co-operation & Development (OECD) https://www.oecd.org/fr/

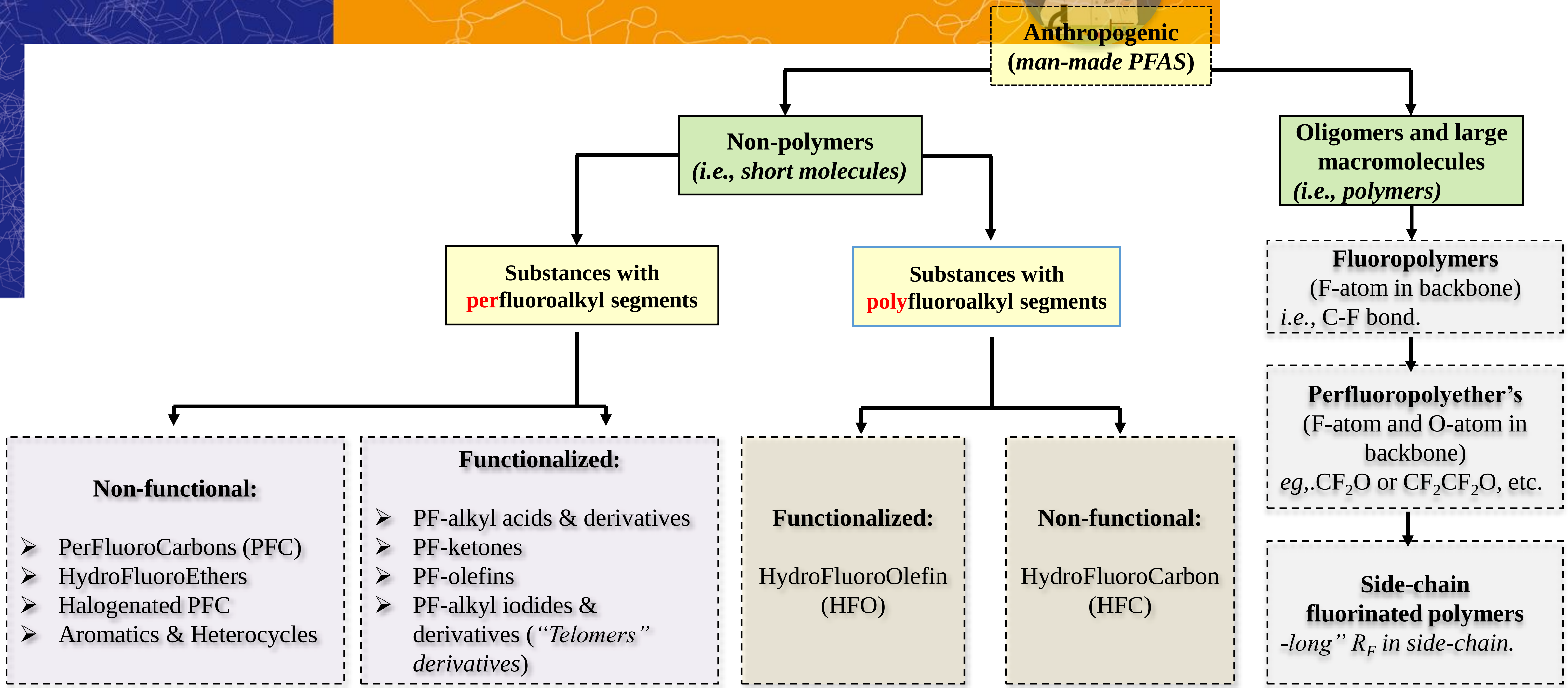
Dalmjin et al. ***Environ. Sci.: Proc. Impacts,*** **2024, 26, 269**

Fast Increase of Number of Articles & Citations



Z. Yin, Water, 2025, 17, 6

Classification of PFAS and *its families*

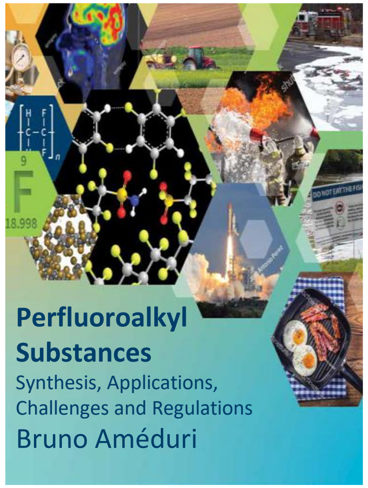


Mueller, Conventions and Physical and Chemical Properties of PFAS,
Interstate Technology Regulatory Council, April 2020

Applications of PFASs

Nonstick cookware,
Grease-resistant and waterproof coatings on food packaging (e.g., popcorn bags, takeout containers, and fast food wrappers),

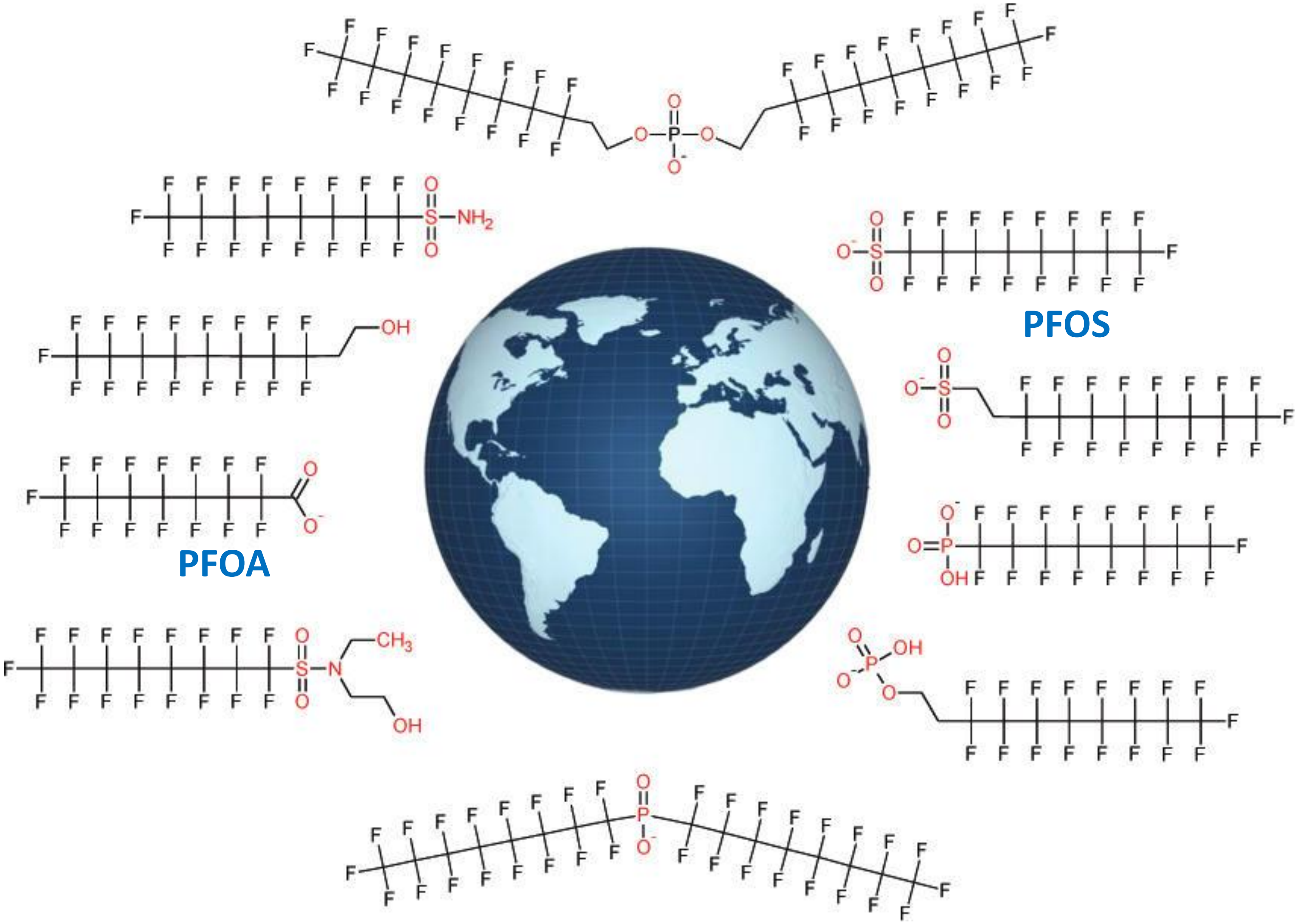
Surfactants for Emulsion Polymerization $C_8F_{17}SO_3H$ (PFOS) $C_7F_{15}CO_2H$ (PFOA)
Coated paper products,
Waterproof, water-resistant, and stain-resistant textiles (e.g., clothing, shoes, upholstery, and carpets)
Cosmetics and personal care products,
Industrial and household cleaning products,
Floor, car, boat and ski waxes,
Engineered coatings used in semiconductor production,
Metal plating and finishing,
Etching of metals, plastics, and glass,
Additives for plastics, resins, and rubber products,
Surface coating, paint, varnish, and inks,
Aqueous Film-Forming Foam (AFFF) used to extinguish flammable liquid fires
F-Materials



From Department of Energy and Environmental Protection

https://portal.ct.gov/DEEP/Remediation--Site-Clean-Up/Contaminants-of-Emerging-Concern/Per--Polyfluoroalkyl-Substances

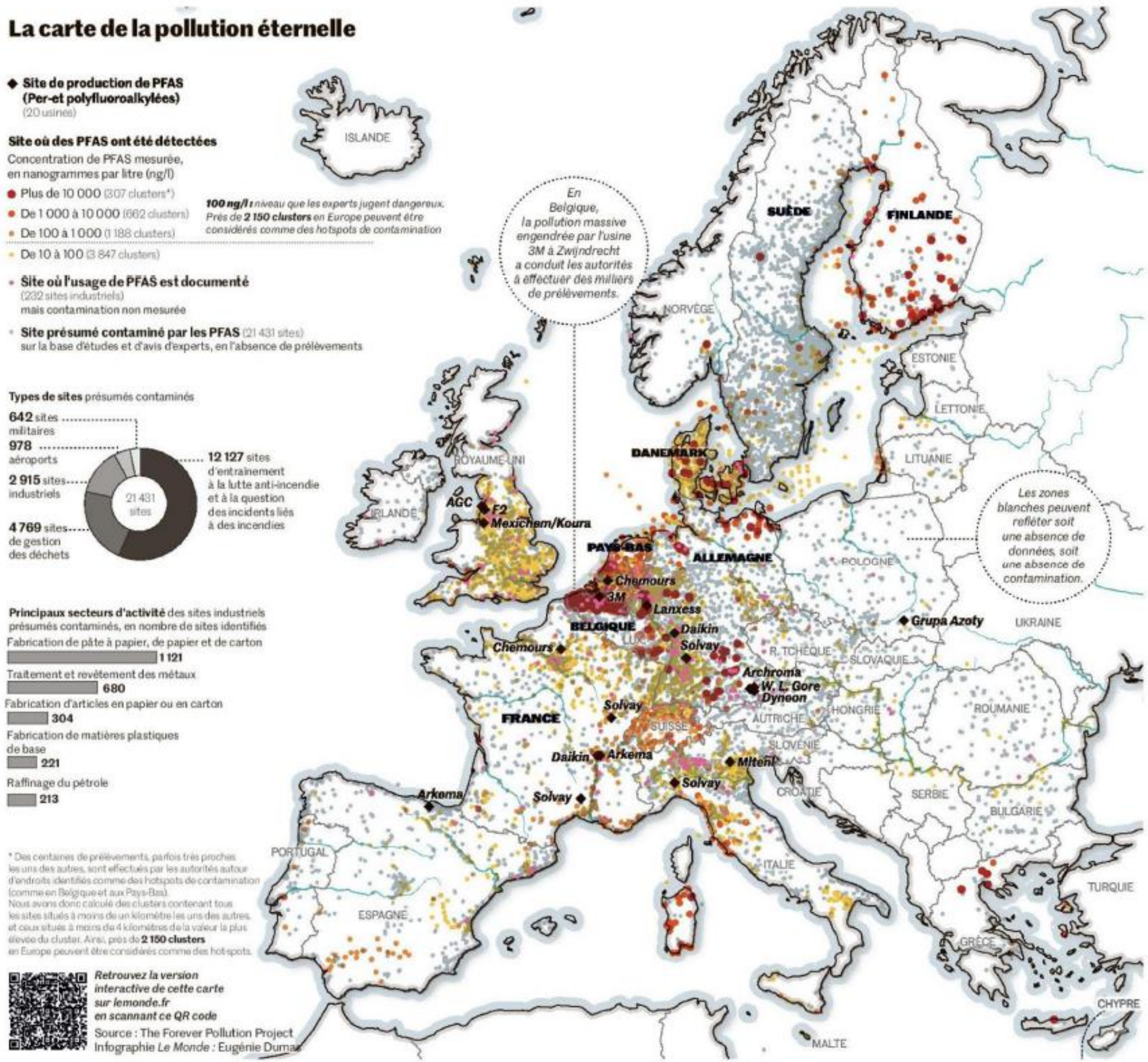
Low-Molar Mass PFASs (Examples of F-Surfactants)



Water Soluble
Mobile
Persistent
Bioaccumulative
Toxic
Cross the Membrane

« Forever Chemicals »
MAIN ISSUES
RESTRICTION

https://portal.ct.gov/DEEP/Remediation--Site-Clean-Up/Contaminants-of-Emerging-Concern/Per-Polyfluoroalkyl-Substances


La carte de la pollution éternelle
◆ Site de production de PFAS (Per-et polyfluoroalkylées) (20 usines)
Site où des PFAS ont été détectées
Concentration de PFAS mesurée, en nanogrammes par litre (ng/l)
Plus de 10 000 (307 clusters*)
De 1 000 à 10 000 (662 clusters)
De 100 à 1 000 (1 188 clusters)
De 10 à 100 (3 847 clusters)
100 ng/l : niveau que les experts jugent dangereux. Près de 2 150 clusters en Europe peuvent être considérés comme des hotspots de contamination
Site où l'usage de PFAS est documenté (232 sites industriels) mais contamination non mesurée
Site présumé contaminé par les PFAS (21 431 sites) sur la base d'études et d'avis d'experts, en l'absence de prélèvements
Types de sites présumés contaminés
642 sites militaires
978 aéroports
2 915 sites industriels
4 769 sites de gestion des déchets
21 431 sites
12 127 sites d'entraînement à la lutte anti-incendie et à la question des incidents liés à des incendies
Principaux secteurs d'activité des sites industriels présumés contaminés, en nombre de sites identifiés
Fabrication de pâte à papier, de papier et de carton 1 121
Traitement et revêtement des métaux 680
Fabrication d'articles en papier ou en carton 304
Fabrication de matières plastiques de base 221
Raffinage du pétrole 213
* Des centaines de prélèvements, parfois très proches les uns des autres, sont effectués par les autorités autour d'endroits identifiés comme des hotspots de contamination (comme en Belgique et aux Pays-Bas). Nous avons donc calculé des clusters contenant tous les sites situés à moins de un kilomètre les uns des autres, et ceux situés à moins de 4 kilomètres de la valeur la plus élevée du cluster. Ainsi, près de 2 150 clusters en Europe peuvent être considérés comme des hot-spots.
Retrouvez la version interactive de cette carte sur lemonde.fr en scannant ce QR code
Source : The Forever Pollution Project
Infographie Le Monde : Eugénie Dumas
En Belgique, la pollution massive engendrée par l'usine 3M à Zwijndrecht a conduit les autorités à effectuer des milliers de prélèvements.
Les zones blanches peuvent refléter soit une absence de données, soit une absence de contamination.
ISLANDE
SUÈDE
FINLANDE
NORVÈGE
ESTONIE
LETTONIE
LITUANIE
DANEMARK
ROYAUME-UNI
IRLANDE
AGC
F2
Mexichem/Koura
PAYS-BAS
ALLEMAGNE
POLOGNE
Chemours
3M
Lanxess
BELGIQUE
LUX.
Daikin
Solvay
Grupa Azoty
UKRAINE
R. TCHÈQUE
SLOVAQUIE
Archroma
W. L. Gore
Dyneon
AUTRICHE
HONGRIE
ROUMANIE
FRANCE
SUISSE
SLOVÉNIE
Arkema
Miteni
CROATIE
SERBIE
BULGARIE
PORTUGAL
ESPAGNE
ITALIE
GRÈCE
TURQUIE
CHYPRE
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PFAS in German children: Human biomonitoring data highlight urgent need for group restriction

July 23, 2020 By Eleanor Hawke

Food Packaging Forum

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NEWS

High PFAS blood levels in German children

Biomonitoring study by *German Environment Agency (UBA)* measures 12 per- and polyfluoroalkyl substances (PFAS) in blood plasma of children and adolescents; finds highest average levels of perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), and perfluorohexane sulfonic acid (PFHxS)

July 6, 2020 | Justin Boucher | 2 minutes

On June 1, 2020, scientists from the *German Environment Agency (UBA)* published an article in the peer-reviewed *International Journal of Hygiene and Environmental Health* presenting results of a biomonitoring study quantifying the presence of per- and polyfluoroalkyl substances (PFAS) in blood plasma of children and adolescents in Germany. The study was carried out in 2014-2017 as part of the 5th cycle of the German Environmental Survey (GerES V), which focused on PFAS exposure of children and adolescents aged 3-17 years old. Twelve PFAS were analyzed in 1,109 blood plasma samples, and the highest mean concentrations were found for perfluorooctane sulfonic acid (PFOS; CAS 1763-23-1) at 2.49 ng/mL, perfluorooctanoic acid (PFOA; CAS 335-67-1) at 1.12 ng/mL, and perfluorohexane sulfonic acid (PFHxS; CAS 355-46-4) at 0.36 ng/mL. The concentrations for all the other PFAS were much lower. 100% of all children in the study had measurable levels of PFOS and 86% had measurable levels of PFOA.

The authors write that "the results document a still considerable exposure of the young generation to the phased out chemicals PFOS and PFOA" and note that the levels "vary substantially" between individuals and could be influenced by different and multiple exposure sources. While further research is needed to understand the different exposure sources, the authors believe the results already emphasize "the need for an effective and sustainable regulation of PFAS as a whole."

Commenting in the press release for the study, Dirk Messner, President of *UBA*, said "which damages the long-lived PFAS can cause in the environment in the long-term is often still unexplored. We are therefore trying, together with

Related articles

- Widespread presence of PFAS in U.S. drinking water
- Retailer initiative, Hollywood film draw attention to PFAS pollution
- EFSA publishes scientific opinion on PFAS in food
- What U.S. states consider in regulating PFAS
- Study finds PFAS with carcinogenic characteristics
- Sweden identifies PFAS as priority risk area
- UK recognizes importance of grouping PFAS
- Public consultation to inform broad EU PFAS restriction
- Denmark moves ahead with PFAS ban in FCMs
- NGOs call for lower PFHxA concentration limit
- *OECD* and *ILSI* hold PFAS virtual events
- *ECHA* online event discusses legislation goals
- *ECHA* committees reach consensus on PFHxS but not on resorcinol

[PFOA]= 1.12 ng/ml
[PFOS]= 2.49 ng/ml

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The Swinging Sentiment Toward PFAS in Germany

In recent years, the spotlight has turned toward per- and polyfluoroalkyl substances (PFAS), often referred to as "forever chemicals" due to their persistent nature in the environment. These synthetic chemicals, used in everything from non-stick cookware to firefighting foams, have become a growing concern due to their potential health risks and environmental impact. Germany, alongside the broader European Union, has been at the forefront of efforts to regulate and, in some cases, phase out these substances. As the country grapples with the complexities of PFAS regulation, the implications for various industries, including those dependent on these chemicals, are becoming increasingly clear.

PFAS have been integral to many industrial applications for decades, prized for their resistance to heat, water, and oil. However, their widespread use has led to significant environmental contamination, as these substances do not easily break down in nature. In Germany, studies have shown that PFAS can be detected in numerous locations, from remote areas to densely populated cities. Concerns about their presence in drinking water, soil, and even human blood have fueled calls for stricter regulation.

Germany's approach to PFAS regulation reflects its broader environmental and public health priorities. The country has long been a leader in environmental protection within the European Union, and its stance on PFAS is no exception. In recent years, German authorities have pushed for a more comprehensive ban on PFAS across the EU, arguing that the potential risks to human health and the environment outweigh the benefits of continued use. The German Federal Environment Minister, Steffi Lemke, has been particularly vocal about the need for stringent controls, highlighting the presence of PFAS even in remote regions like the Antarctic as evidence of their pervasive threat.

The push for regulation gained momentum in 2023 when several European countries, including Germany, proposed a near-total ban on the manufacture, use, and marketing of PFAS within the EU. This proposal, currently under review by the European Chemicals Agency (ECHA),

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The push for regulation gained momentum in 2023 when several European countries, including Germany, proposed a near-total ban on the manufacture, use, and marketing of PFAS within the EU. This proposal, currently under review by the European Chemicals Agency (ECHA), includes transition periods of up to thirteen years for certain applications, acknowledging the challenges industries face in finding suitable alternatives. However, the proposed ban also makes allowances for specific uses where no viable alternatives exist, such as in medical devices and other critical technologies.

Despite these exemptions, the proposed regulations have sparked concern across various sectors, particularly in industries where PFAS are considered essential. The German industry, especially the automotive and chemical sectors, has warned that a blanket ban could have far-reaching consequences for the country's economy and its transition to climate-neutral technologies. PFAS are crucial components in the production of semiconductors, electric vehicles, and renewable energy infrastructure—key elements in Germany's strategy to combat climat change.

Economics Minister Robert Habeck has cautioned against "overregulation," emphasizing the need for a balanced approach that protects both public health and industrial innovation. He has advocated for a differentiated regulatory framework that allows for the continued use o PFAS in areas where no alternatives currently exist and where the substances pose minimal risk to human health and the environment. This approach aims to avoid stifling technological development while still addressing the environmental concerns associated with PFAS.

For industries like consumable chromatography testing using silicone/PTFE lined cap manufacturing, which rely on the unique properties of PFAS to ensure product quality and safety, the evolving regulatory landscape presents both challenges and opportunities. While the potentia for stricter regulations may necessitate changes in materials and processes, it also opens the door for innovation in the development of safer, more sustainable alternatives. Manufacturers will need to stay ahead of regulatory changes, investing in research and development tc find new ways to meet performance standards without relying on PFAS.

The ongoing debate in Germany and the EU over PFAS regulation underscores the complexity of balancing environmental protection with industrial needs. As the world moves toward a more sustainable future, the challenge will be to manage this transition in a way that

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TRY: MOLECULES TO MATERIALS

Carcinogenicity of perfluorooctanoic acid and perfluorooctanesulfonic acid

www.thelancet.com/oncology Vol 25 January 2024

PFOA was classified as "carcinogenic to humans" (Group 1) based on "sufficient" evidence for cancer in experimental animals and "strong" mechanistic evidence in exposed humans. The evidence for cancer in experimental animals was "sufficient" because an increased incidence of an appropriate combination of benign and malignant neoplasms was observed in both sexes of a single species in a Good Laboratory Practice (GLP) study. The mechanistic there was "limited" evidence for cancer in humans for renal cell carcinoma and testicular cancer. PFOS was classified as "possibly carcinogenic to humans" (Group 2B) based on "strong" mechanistic evidence. The evidence for cancer in experimental animals was "limited" for PFOS, and the evidence regarding cancer in humans was "inadequate". These assessments will be published in Volume 135 of the *IARC Monographs*.[1]

What's new?

Perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are two environmental endocrine-disrupting chemicals suspected to be ubiquitously present in the blood of the human population. This nested case-control study including non-occupationally exposed postmenopausal French women suggests a linear dose-response relationship between PFOS serum concentrations and the risk of developing hormone receptor-positive breast cancer. Furthermore, an increased risk of developing ER– and PR– tumors is associated to middle-low serum concentrations of PFOA and PFOS. Exposure to endocrine-disrupting chemicals should be considered as a potential risk factor for breast cancer, thus a serious public health issue.

Mancini et al., Int. J. Cancer: 146, 917–928 (2020)

iCGM
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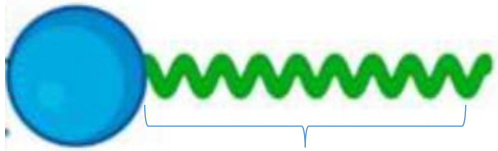
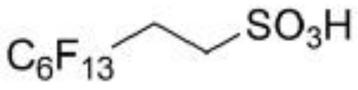
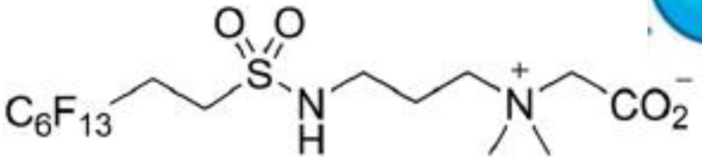
...CULES TO MATERIALS



Short-chain fluorosurfactants

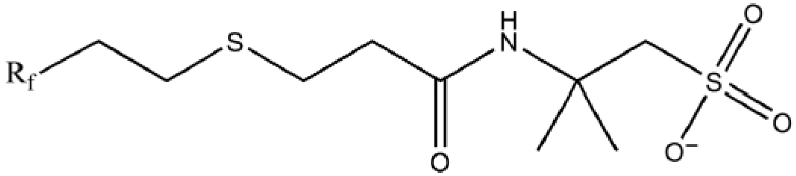


Atotech Fumetrol 21
1



Chemours Capstone 1157
2

Fluoroether surfactants



$CF_3CF_2CF_2OCF(CF_3)COONH_4$

Dupont/Chemours GenX
3

$CF_3OCF_2CF_2CF_2OCHFCF_2COONH_4$

3M ADONA
6

$CF_3OCF(CF_3)CF_2OCF(CF_3)COONH_4$

Daikin PFDMO2HpA
4

$Cl(CF_2CF_2)_3OCF_2CF_2SO_3K$

F-53B
7

$CF_3CF_2OCF_2CF_2OCF_2COONH_4$

AGC APFDO
5

Regrettable Substitutes

J. AWWA 2018, 110, 13-28

$C_4F_9SO_2NH(CH_2)_3N^+(CH_3)_3I^-$ (cationic) and $C_3F_7COO^-Na^+$ (anionic)

DX1030 (anionic), Capstone 1157 (amphoteric), and DX2200 (non-ionic) Lodyne S-103A

Y. Guo et al., Chapter 5, in B. Ameduri PFAS: Regulations, Synthesis and Applications, RSC, 2022

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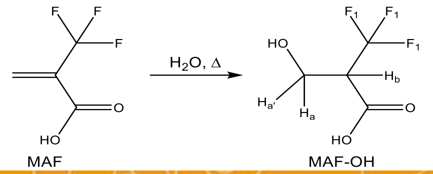
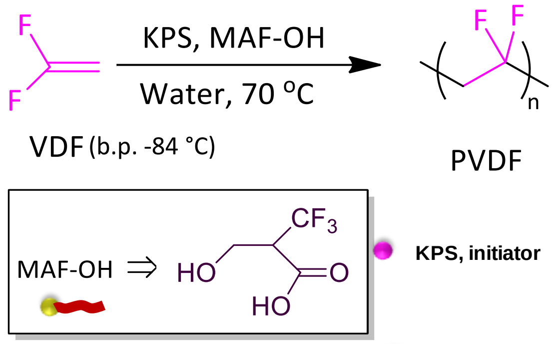
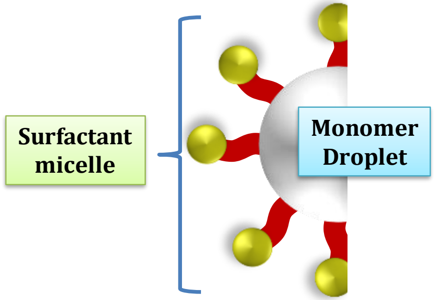
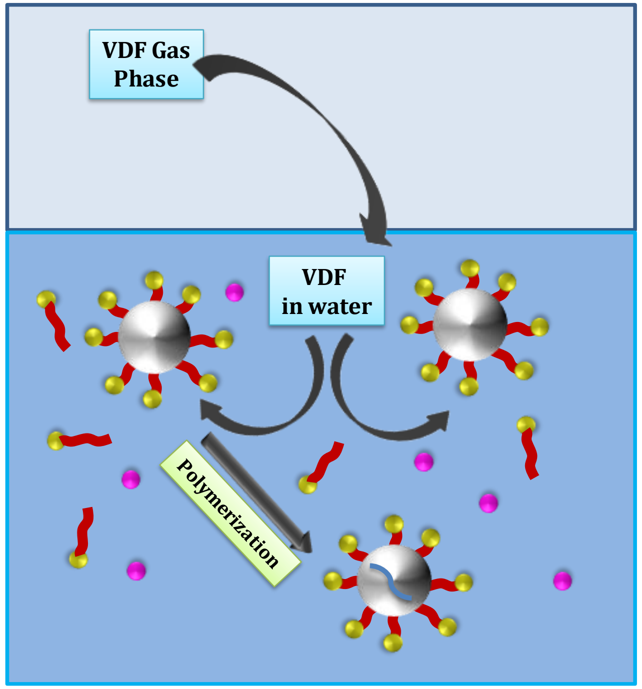
Radical Polymerization in Aqueous System

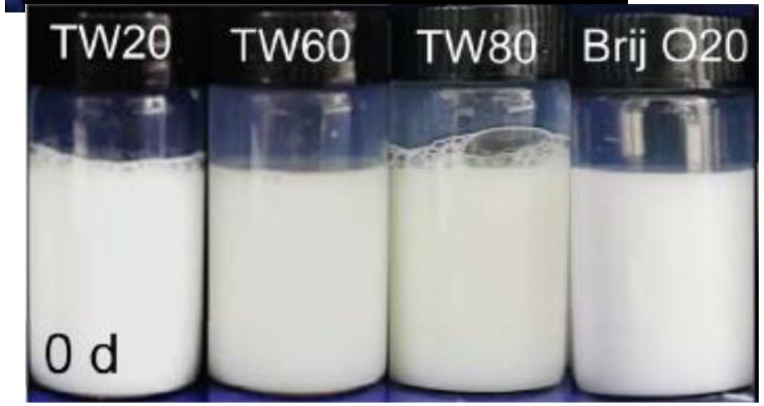


CHEMISTRY: MOLECULES TO MATERIALS

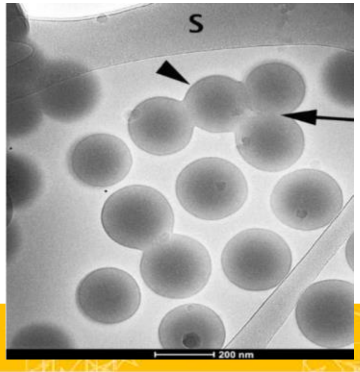


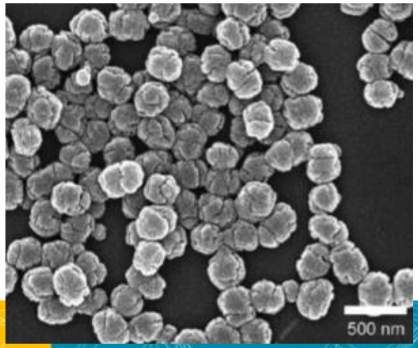






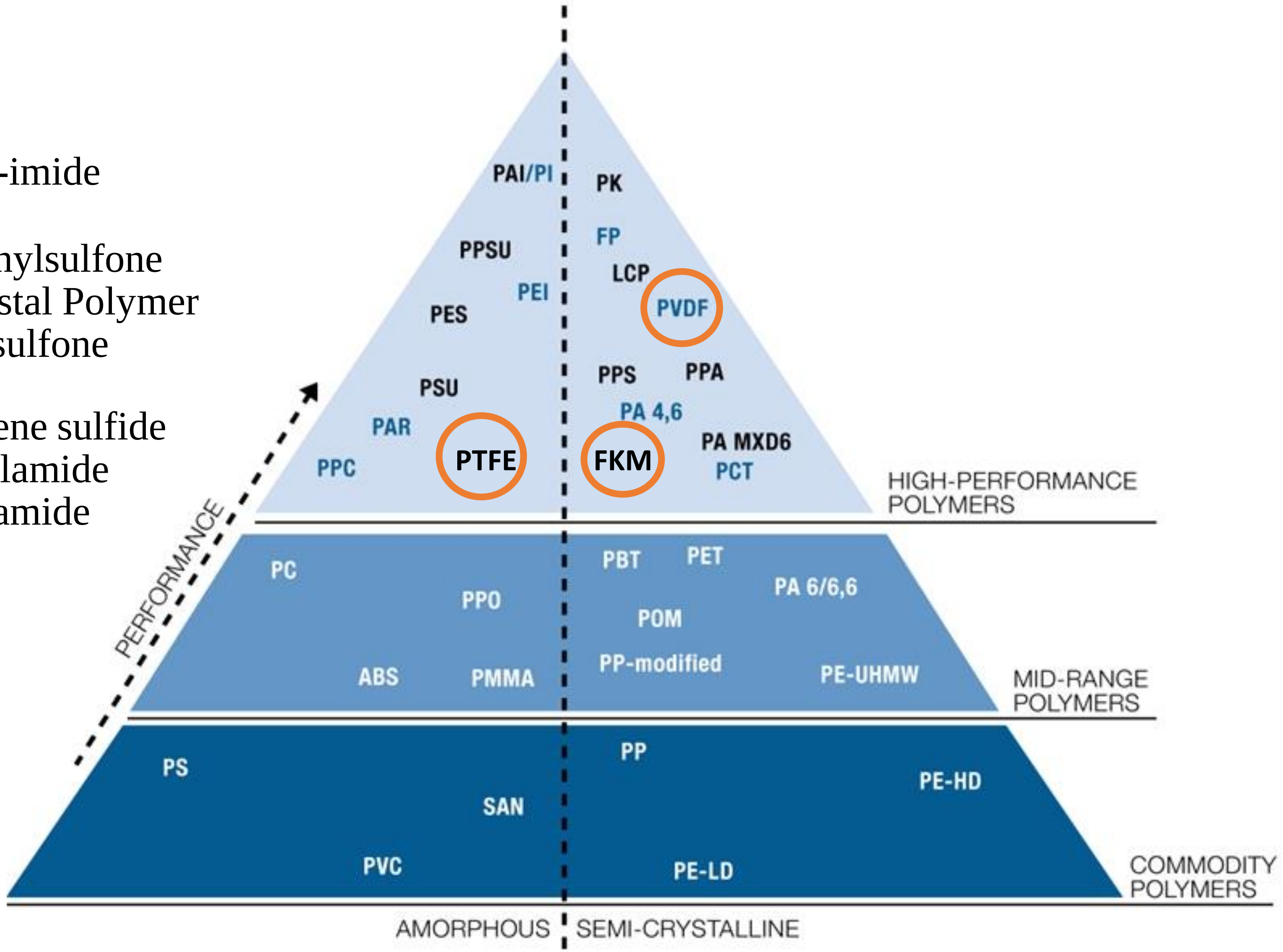
Chem. Comm. 2018





THE POLYMER PYRAMID

PAI = TORLON® polyamide-imide
PK = KADEL® polyketone
PPSU = RADEL® R polyphenylsulfone
LCP = XYDAR® Liquid Crystal Polymer
PES = RADEL® A polyethersulfone
PSU = UDEL® polysulfone
PPS = PRIMEF® polyphenylene sulfide
PPA = AMODEL® polyphthalamide
PA MXD6 = IXEF® polyarylamide



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Properties and Advantages of Fluoropolymers

CHEMISTRY: MOLECULES TO MATERIALS

Low refractive index → Optical Fibers & Coatings

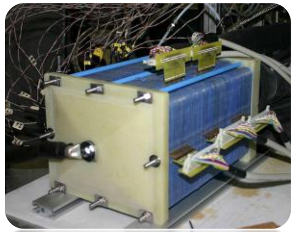
Low surface energy → Lubricity, Release

High oil, water & soil repellency → Protection of Textiles, Leather, Paper, Wood, Glass, Concrete, Stone, Metal

High chemical, thermal, oxidative stability → Protective Coatings

Robustness, Inertness & Stability → Gas Separation and Water Purification

Electrochemical Stability → Li Ion Batteries & Proton Exchange Membranes



Insulation → Wire and Cable Industries

Electroactive → Sensors, Haptics, Actuators, Transducers, etc..

B. Ameduri, S. Fomin, 2020, *Fascinating Fluoropolymers: Vol 2 (Applications)*, Elsevier

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Fluoropolymer Market US$ 10 billion in 2023. Expected: US$ 18 billion by 2033

https://www.futuremarketinsights.com/reports/fluoropolymers-market

CHEMISTRY: MOLECULES TO MATERIALS

Where Can You Find PFAS in Automotives?

Automotive PFAS applications

Power Trains
- Internal shift seal rings
- Hydraulic clutch piston rings
- Transaxle components

Engine
- Head gaskets
- Crankshaft rotary seals
- Valve stem seals
- Air conditioner piston rings
- Hot air turbo diesel duct

Control Cable Liners
- Accelerator
- Shift
- Brake
- Cruise Control

Chassis
- Shock absorber piston seals
- Stabilizer bar bushing
- Steering ball joint insert
- Steering assist pump piston rings

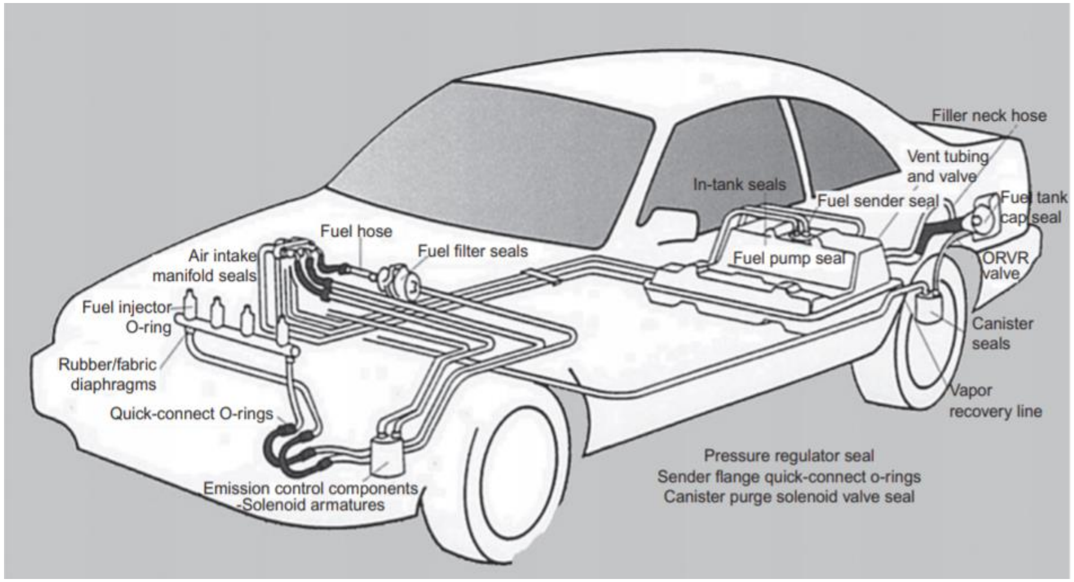
Other
- Wire and cable insulation
- Shaft seals
- Valve stem seals
- Fuel inject O-rings
- Fuel hoses
- Fuel system seals
- Upholstery
- Balls for check valves
- Batteries
- Windshield

Dispersions and Coatings
- Weld nuts
- Air conditioning piston
- Springs
- Hose clamps
- Carburetor parts
- Hinge pins
- Nuts and bolts
- Seat belt hanger
- Intake valve
- Clutch plates
- Steering column slip shafts

Brake Systems
- ABS interconnect hose
- Impulse hose at wheel
- Brake pad wear indicator

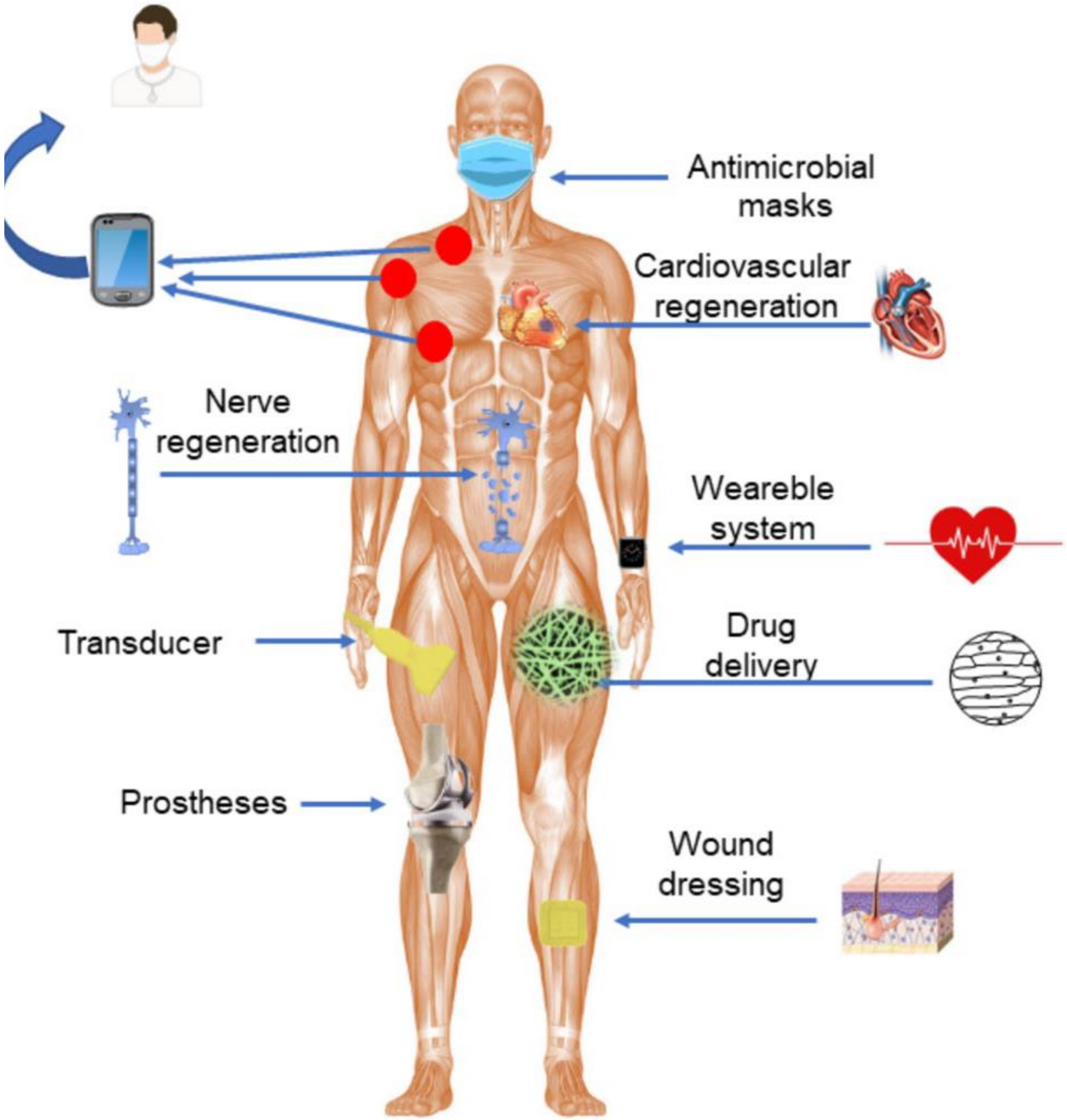
Requirements:
- Security
- Chemical and thermal Resistances
- Low Friction Properties

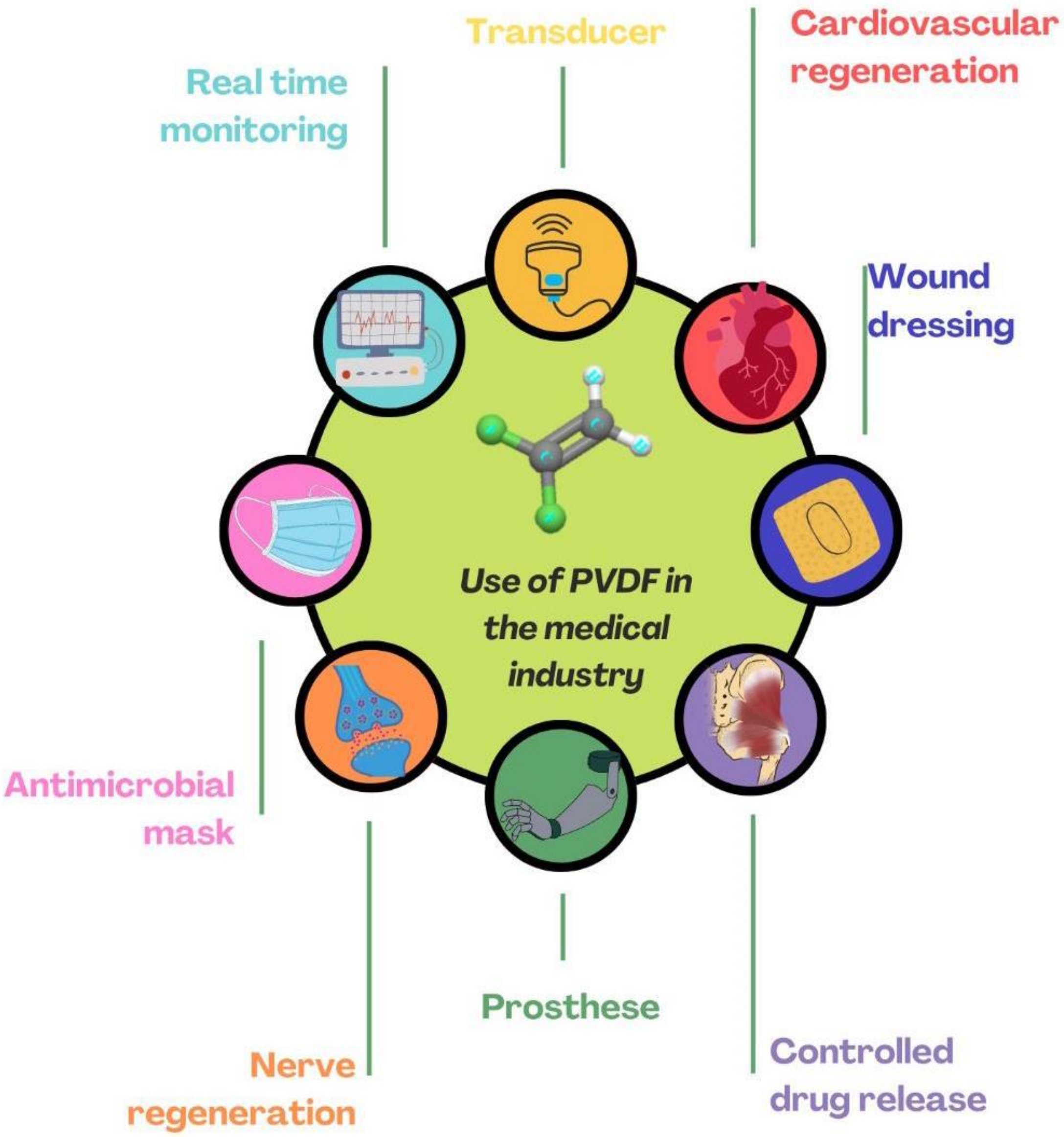
- **Searched Values**
- **Reliability, efficency, safety of Vehicles**



A.L. Moore, *Fluoroelastomers Handbook*, Elsevier, 2006

PVDF Applications in the Biomedical Area





Concha et al., *J Mater Sci* (2024) 59:14185–14204

PTFE (Polytetrafluoroethylene; Teflon®)

LL Radulovic and ZW Wojcinski, Drug Development Preclinical Services, LLC, Ann Arbor, MI, USA

Encyclopedia of Toxicology, 2014, 3, 1133-1137

Uses

PTFE has a wide range of commercial uses such as electrical cable insulation, soil and stain repellant for fabrics, coating for nonstick cookware and surgical implants, sutures, aneurysm clips, vascular grafts, dental applications, liner for vessels/containers, lubricant, filter, and as prosthetic material. Teflon® is used in pesticides as an inert ingredient. Perfluorocarbon resins may be safely used as articles or components of articles intended to contact food (i.e., indirect food additives as basic components of single and repeated use food contact surfaces) (FDA 21CFR177.1550).

Environmental Fate and Behavior

PTFE is the most stable of all TFE polymers and under physiological conditions does not release any components (IARC Monograph 74, 1999). PTFE is very inert chemically; only alkali metals and fluorine under pressure attack PTFE (Hazardous Substances Data Bank (HSDB)). There are no known ecotoxicological effects for PTFE (DuPont MSDS, 2011).

Exposure and Exposure Monitoring

The most common source of PTFE exposure is the workplace. Teflon® dust has been detected in workplace environments

Toxicokinetics

The physicochemical properties of PTFE, including it being a solid, stable under physiologic conditions, and not metabolized, preclude any toxicokinetic analysis. Thus, toxicokinetics data for PTFE are not found in the literature.

Mechanisms of Toxicity

There is no apparent mechanism of toxicity for orally administered PTFE as no toxicologically significant effects were observed following oral administration to rats for up to 90 days. The lack of toxicity is most likely due to the following: (1) gastrointestinal absorption of PTFE is negligible given its extremely high molecular weight (1 000 000–10 000 000 for PTFE fine powder); (2) PTFE is chemically inert under physiologic conditions; and (3) PTFE is not metabolized (Donovan et al., 1990; Kim, 1996; Veber et al., 2002). The mechanism of action of subcutaneously injected PTFE in mice is attributed to localized inflammation consistent with a foreign-body response; similar effects were seen following subareolar injection in rabbits and dogs, and periurethral injections in dogs.

When PTFE is heated or exposed to temperatures ≥200 °C, it will decompose and release toxic vapors that cause polymer-fume fever in humans.

Acute and Short-Term Toxicity

The oral toxicity of PTFE in rats is low ($LD_{50} > 11\,280$ mg kg^{-1}; DuPont MSDS, 2011). Following repeated dietary administration of up to 25% PTFE to rats for up to 90 days, no toxicologically significant effects were noted (IARC Monograph 19, Supplement 7, 1987; DuPont MSDS, 2011; Haskell Laboratory Report 224-68, 1968). PTFE is not a skin irritant in rabbits or humans, nor is it a skin sensitizer in humans (DuPont MSDS, 2011; Solvay MSDS, 2007).

However, PFIB, a pyrolysis product of PTFE, is very toxic (HSDB, 2013). It is approximately 10 times more toxic to rats than phosgene, with 0.5 ppm PFIB for 6 h being lethal. The LC_{50} values for PFIB in rats vary considerably depending on the duration of exposure: 0.76 ppm for a 4 h inhalation exposure, 17 ppm for a 10 min exposure, and 361 ppm for a 0.25 min exposure (HSBD, 2013).

Pulmonary histopathologic findings reported following acute exposure of rats to 78 ppm PFIB for 1.5 min progressed in nature and severity with time postexposure (Brown et al., 1991 cited from HSBD, 2013). Within 5 min postexposure, changes to the bronchioles and peribronchial alveoli were characterized by alterations to cilial structure, increased pinocytosis and electron lucency, with occasional vesicle formation of type I alveolar epithelial cells. Intercellular leakage with minimal fluid accumulation in the alveolar spaces was also seen. By 2–3 h postexposure, pulmonary edema was noted. Deaths occurred from 7 h and later. Widespread pulmonary edema and alveolar interstitial infiltration by lymphomononuclear cells and macrophages were seen by 24 h following exposure.

Male Fischer 344 rats were exposed to aerosolized products of PTFE heated to 595 °C (equivalent to an LC_{50} dose of 0.045 mg l^{-1} of the PTFE degradation products) for 30 min (Zook et al., 1983). Signs of respiratory impairment were observed in some rats prior to death. Surviving rats were euthanized up to 36 h postexposure and between 2 and 17 days. Pathologic findings include pulmonary edema, focal hemorrhage, and fibrin deposition. Focal interstitial thickenings developed over time as a consequence of hypertrophy and hyperplasia of alveolar cells, and accumulation of macrophages in alveoli. Thrombosis of pulmonary capillaries was a common finding. The incidence (53%) and severity of disseminated intravascular coagulation (DIC) in rats exposed to PTFE aerosolized products were positively related to the degree of pulmonary damage. Renal infarcts were also common and due to DIC. There were no lesions observed in kidney or other tissues (except lung and thymus) unless affected by DIC.

Although PTFE is inert under ordinary circumstances, polymer-fume fever could result when PTFE polymer is heated to 315–375 °C under conditions of inadequate ventilation. Exposure to the resulting fumes may cause chills, fever, profuse sweating, cough, dyspnea, flu-like symptoms, and chest tightness, lasting for 24–48 h. Respiratory discomfort and pulmonary function abnormalities may persist for several weeks after exposure. Pulmonary edema is more likely to occur with exposure to fumes generated from heating PTFE at ≥500 °C.

Some PTFE decomposition products are epidermal, mucosal, and ocular irritants. A pungent or metallic smell and a metallic taste may occur in patients with polymer-fume fever. Effects of polymer-fume fever may also include nausea and vomiting; headache; weakness; malaise; mild hypoxia; paresthesias; hyperpyrexia; leukocytosis; pulmonary infiltrates; mild sinus tachycardia; reversible mild hypertension; pneumonitis; and noncardiogenic pulmonary edema.

A fatality of a plastics worker and hospitalization of two other workers exposed to PTFE heated in a plastic extruding operation were reported in 1997 (Lee et al., 1997). The plastics worker died from profound hypoxemia, as a consequence of pulmonary edema, and shock shortly after hospital admission. The other two exposed workers were released following medical treatment.

Chronic Toxicity

In humans, sequelae following multiple episodes of polymer-fume fever have included more chronic pulmonary effects, e.g., prolonged decreases in diffusing capacity, reversible obstructive changes, and possibly fibrosis.

Subcutaneous injection in mice, subareolar injection in rabbits and dogs, and periurethral injections in dogs of PTFE followed for up to 1 year revealed a persistent chronic inflammatory reaction at the injection site that exhibited progressive growth with time (Kossovsky et al., 1991).

Immunotoxicity

Although localized inflammation, characterized by presence of eosinophils, lymphocytes, plasma cells, macrophages, and/or giant cells, was elicited by subcutaneous injection in mice, subareolar injection in rabbits and dogs, and periurethral injections in dogs of PTFE, these responses are not classically considered immunotoxic but are more consistent with a foreign body reaction.

In rats exposed to PTFE fumes generated by heating to temperatures of 450–460 °C for 15 min, increases of 5-, 15-, 10-, 40-, 40-, and 15-fold was noted for messages encoding for nitric oxide synthase, interleukin 1α, 1β, and 6, macrophage inflammatory protein-2, and tumor necrosis factor α, respectively. These results indicate that PTFE fumes can elicit a severe localized pulmonary inflammatory response (Johnston et al., 1996).

Genotoxicity

Although no data on the genotoxicity of PTFE could be found in the literature, the monomer of PTFE, tetrafluoroethylene (TFE), is not considered genotoxic. TFE did not induce micronuclei in mouse erythrocytes and its metabolite, tetrafluoroethylcysteine, was not mutagenic in *Salmonella typhimurium* (NTP TR 450 Report, 1979).

Carcinogenicity

Following subcutaneous implantation of a PTFE sheet, disc, or fragment in different strains of the mice, the incidence of localized fibrosarcomas was up to 22.7% in Swiss mice, up

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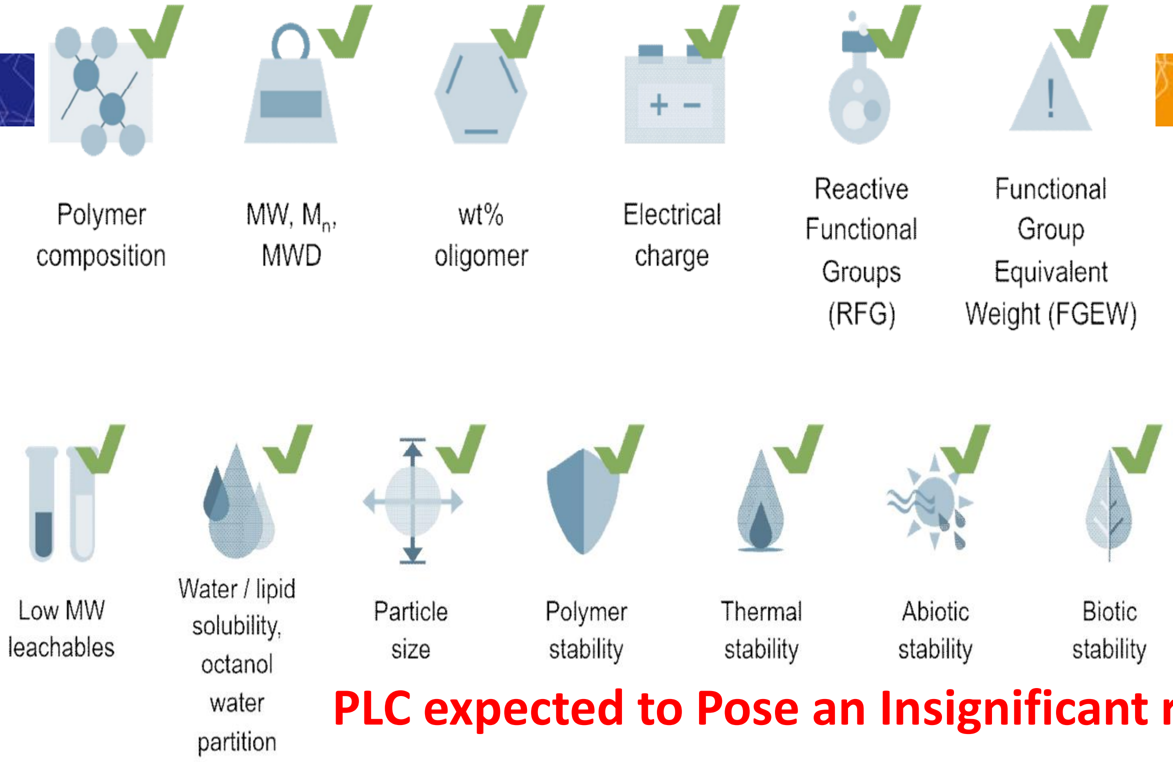
CHEMISTRY: MOLECULES TO MATERIALS

13 « Polymer of Low Concern » Criteria



PLC expected to Pose an Insignificant risk to Human Health & the Environment

Fluoropolymers are:

- **Non-toxic**
- **Non-bioaccumulative**
- **Non-mobile**
- **Insoluble in Water**
- **Stable – Thermally, Chemically & Biologically**
- **Durable**
- **Not a Substance of Very High Concern (SVHC)**

B. Henry et al., Integr. Environ. Assessm. Management, 2018, 14, 316–334

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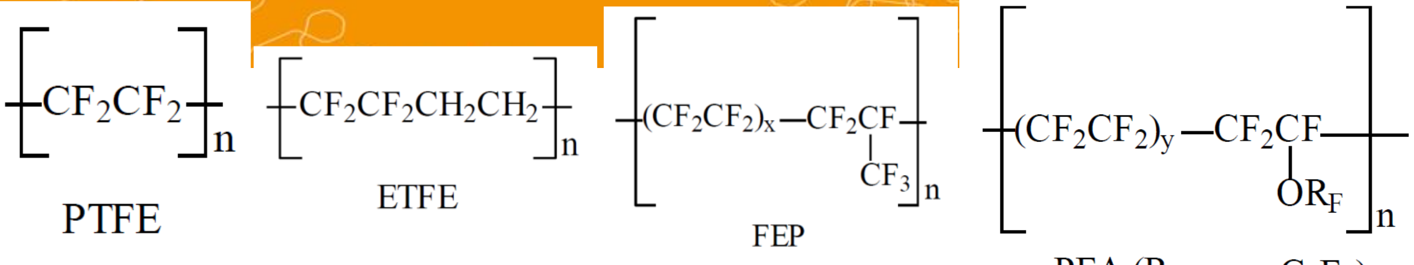
CHEMISTRY: MOLECULES TO MATERIALS

Two Main Reviews on PLC

B. Henry et al., *Integr. Environ. Assess. Manag., 2018*, 14, 316–334

4 Major FPs:



PTFE ETFE FEP PFA (R_F = n—C_3F_7)

Integrated Environmental Assessment and Management — Volume 00, Number 00—pp. 1–30

Received: 9 March 2022 | Revised: 7 June 2022 | Accepted: 7 June 2022

Critical Review *Integr. Environ. Assess. Manag. 2023, 19, 326-54*

A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers

Stephen H. Korzeniowski,[1] Robert C. Buck,[2] Robin M. Newkold,[2] Ahmed El kassmi,[3] Evan Laganis,[3] Yasuhiko Matsuoka,[4] Bertrand Dinelli,[5] Severine Beauchet,[5] Frank Adamsky,[6] Karl Weilandt,[7] Vijay Kumar Soni,[8] Deepak Kapoor,[9] Priyanga Gunasekar,[9] Marco Malvasi,[10] Giulio Brinati,[10] and Stefana Musio[10]

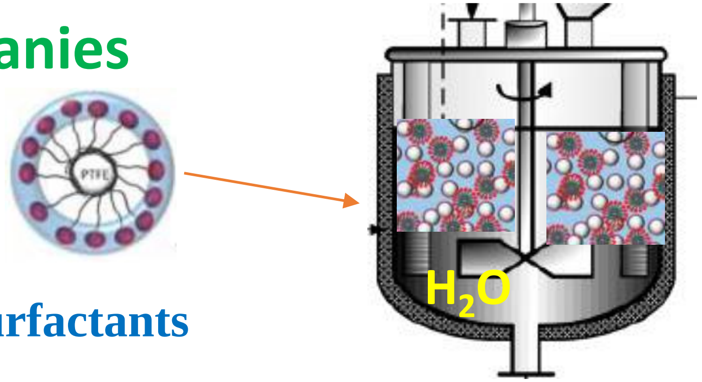
10 Companies= FluoropolymerGroup (FPG)

96% of FPs Fulfill the 13 PLC Criteria

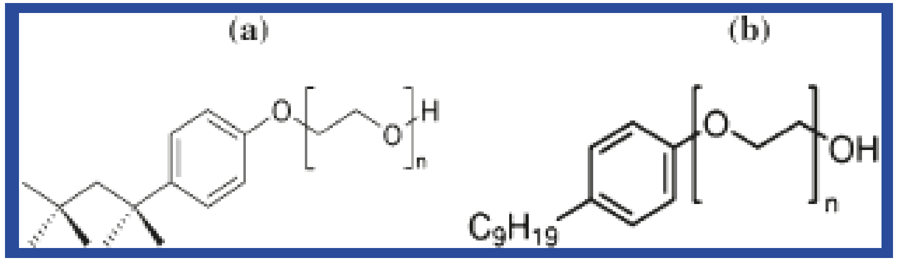
To Make the Adjustments by Seeking New Innovations

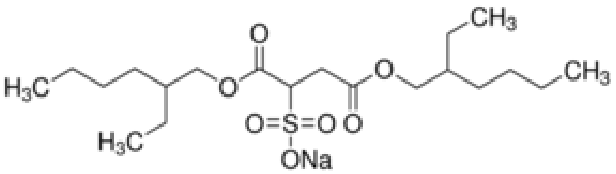
3 actions Taken by FP Manufacturers:

- Use of Non F-Polymerization Aids (Surfactants)
- Abattement of Technologies Reducing PFAS Emissions
- Anouncement of such Innovations by Companies



US8697822B2 Durali, Hedhli, Amin-Sanayei,
Polymerization of fluoropolymers using non-fluorinated surfactants





FLUORO-SURFACTANT FS FREE

Sales, BA et al. Intern. Chem. Regul. Law Rev., 2023, 6, 29

FPG Manufacturing Programme

ICGM Institut Charles Gerhardt Montpellier

PLASTICS EUROPE
Enabling a sustainable future
Fluoropolymers Product Group

ULES TO MATERIALS

The **Manufacturing Programme** includes a concrete commitment to **minimize emissions of non-polymeric PFAS residues from polymerization aids** to the environment from fluoropolymer manufacturing by the following **FPG member companies**: **AGC, Arkema, Chemours, Daikin Chemical Europe, W. L. Gore & Associates and Solvay (Syensqo)**

An industry-led commitment to achieve Average Emissions Factors for non-polymeric PFAS residues from polymerization aid technology that is used in the fluoropolymer manufacturing process

- **By end 2024: 0.009% to air; 0.001% to water**
- **By end 2030: 0.003% to air; 0.0006% to water**

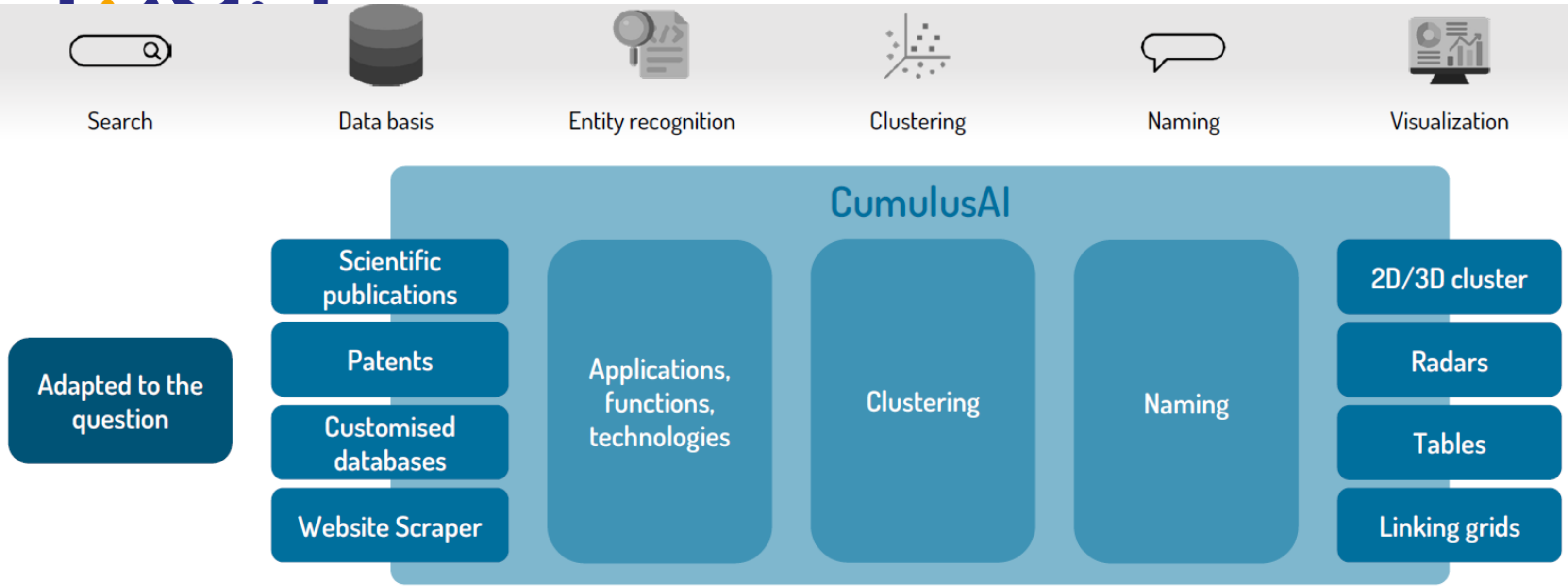
A platform to promote the adoption of commercially available state-of-the-art technologies to minimise non-polymeric PFAS emissions in our manufacturing

A commitment to inform downstream users of fluoropolymers on their safe handling and use in the Guide for the Safe Handling of Fluoropolymer Resins.

The Manufacturing Programme is anchored in three Pillars and its Implementation Began Early January 2024

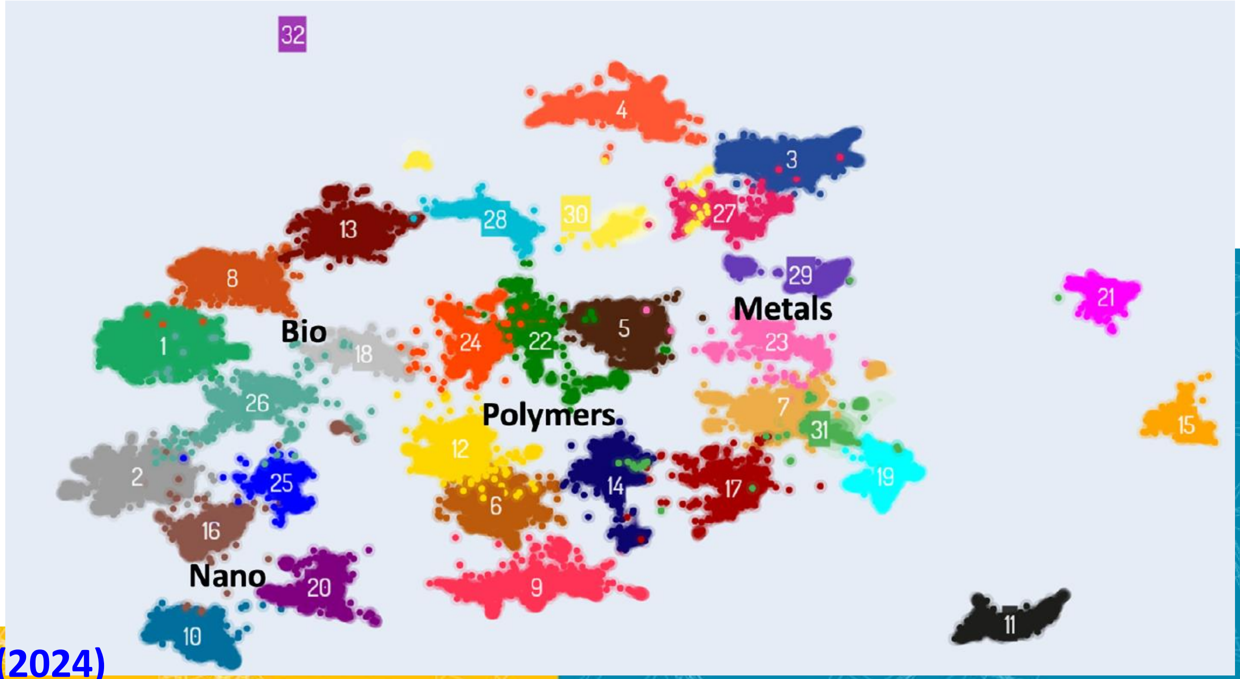
AI: 35,246 individual documents were identified and included in the data pool

CHEMISTRY: MOLECULES TO MATERIALS



Application, Technical functions & Substitution Possibility in Industry
(Carl Zeiss, Novaliq, Mercedes-Benz, Richard Wolf GmbH, key-actors in medical technology, semiconductor manufacturing technology, automotive and pharmaceutical industries)

Potential Alternatives



Required Utility dimensions, 16 Materials Emerged.

2 identified materials have the potential to partially substitute PFAS according to current Standards.
…and No adequate replacement could be found.

C. Lang-Koetz & U. Hutschek, www. Thinktank PFAS-indus strategies (2024)

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Article

An Overview of Potential Alternatives for the Multiple Uses of Per- and Polyfluoroalkyl Substances

Romain Figuière,* Luc T. Miaz, Eleni Savvidou, and Ian T. Cousins

Cite This: Environ. Sci. Technol. 2025, 59, 2031−2042
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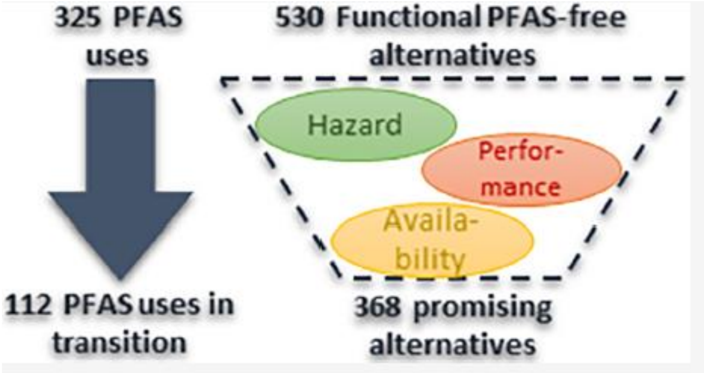
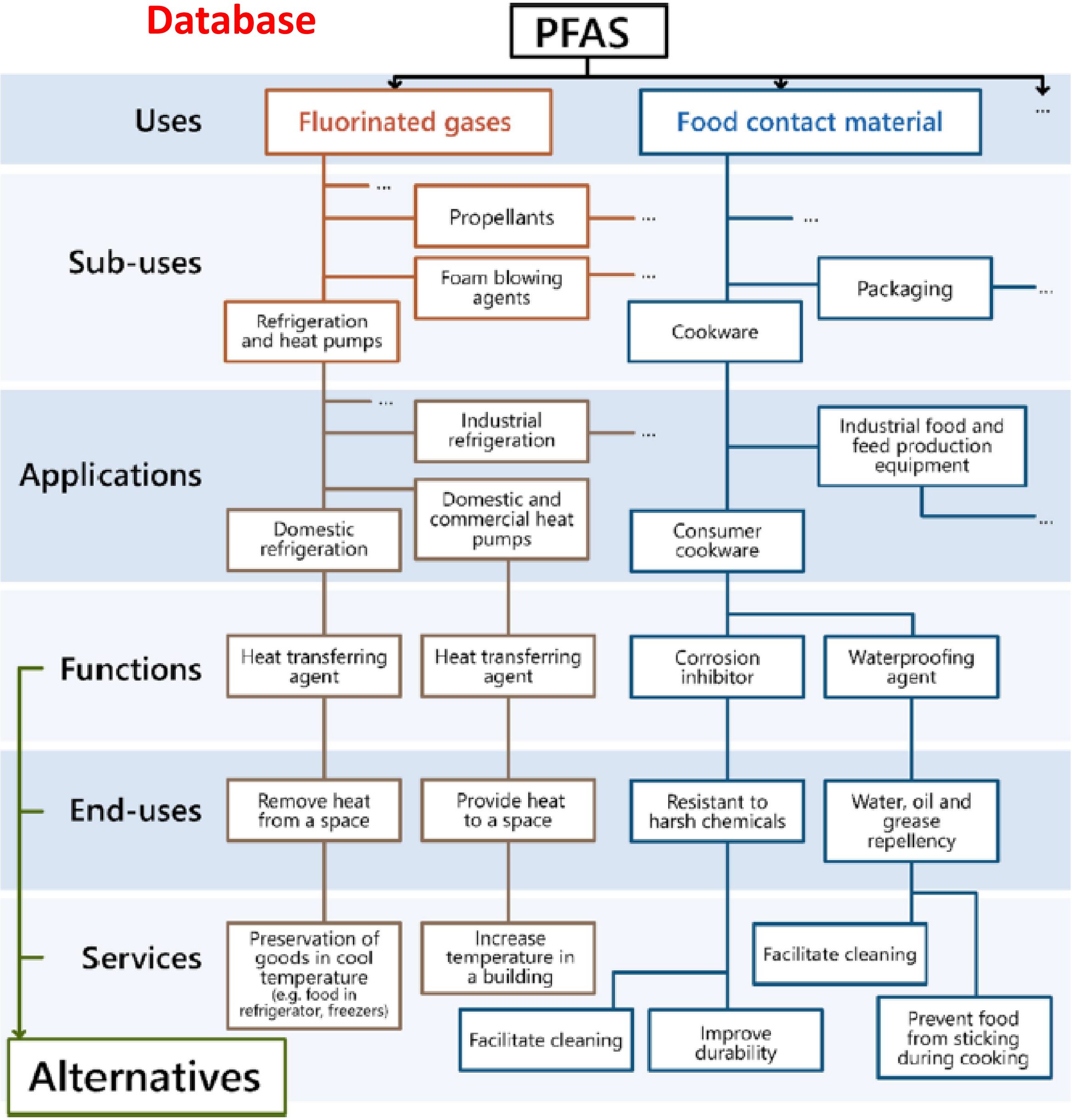


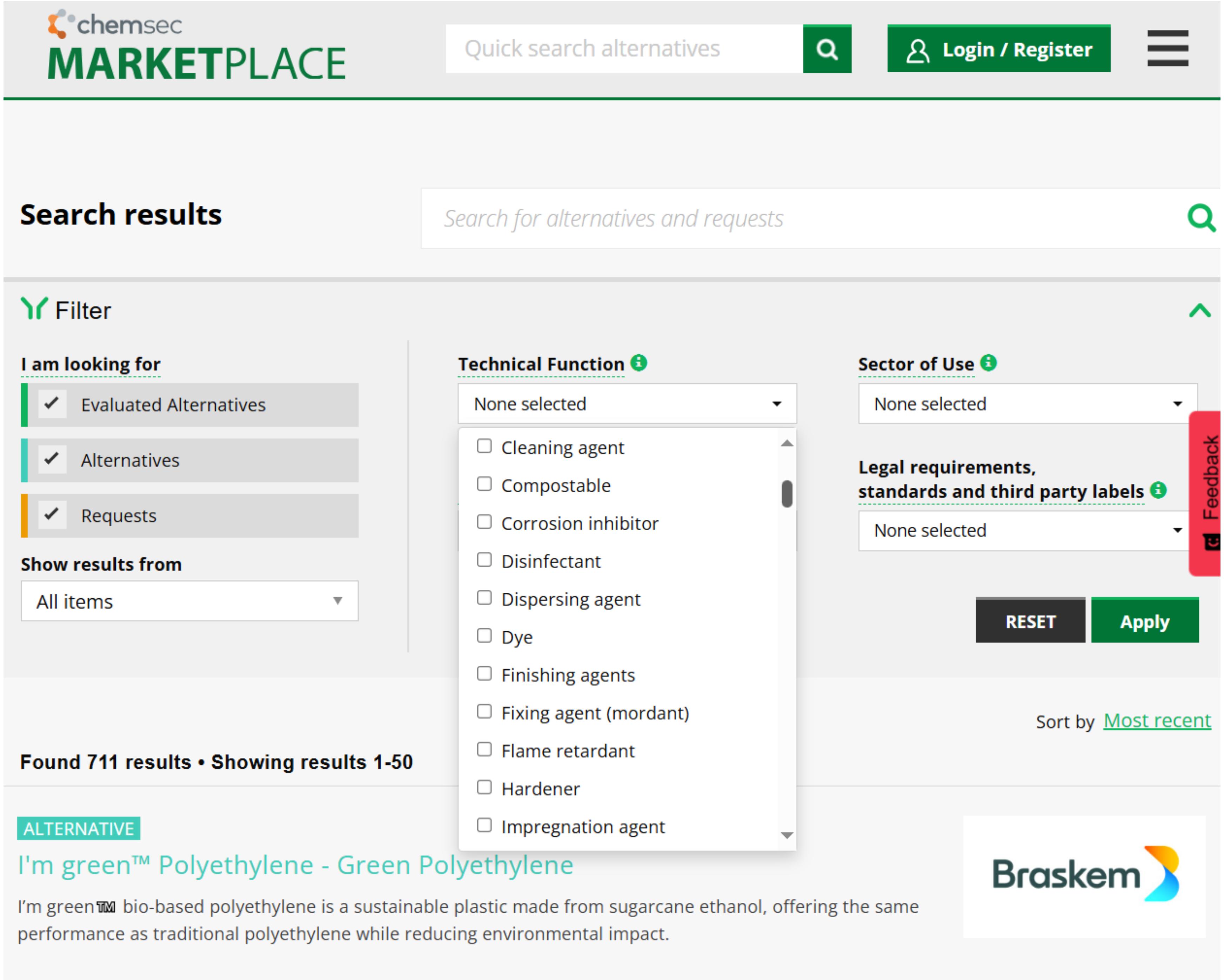
Alternatives for Substances (162)

- Materials (163)
- Products (128)
- Processes (37)
- Technologies (40)

Database



Conclusion: Although efforts made to map all uses of PFAS, work is still needed to provide an overview of their potential alternatives. For 83 applications, no alternatives could be identified….. the focus of further research activities.



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ALTERNATIVE

I'm green™ Polyethylene - Green Polyethylene

I'm green™ bio-based polyethylene is a sustainable plastic made from sugarcane ethanol, offering the same performance as traditional polyethylene while reducing environmental impact.

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Piezoeelctric film

Looking for an alternative to PVDF in a piezoelectric film sensor

EVALUATED ALTERNATIVE

VICTREX PEEK Polymers, High performance engineering plastic

Victrex is a world leader in PEEK and PAEK Polymer solutions. PEEK "polyetheretherketone" polymers, regarded as one of the world's highest performing polymers, support multiple key engineering requirements at the same time with excellent mechanical and wear properties, temperature and chemical resistance, and can meet regulatory standards.

EVALUATED ALTERNATIVE

Non-fluorinated, PFC-free water repellent for all types of fabrics

UNIDYNE XF Series is repellent finish for a wide array of textile substrates that is made from greater than 50% bio-based materials. As with Daikin's long-standing fluorochemical repellents series, XF Series provides

Benefits of PFAS-free & PTFE-free solutions

Clariant's PFAS-free additives offer equal performance to their PTFE-containing predecessors, with lower dosage levels. All tests have demonstrated that our PTFE-alternatives are a viable and safe replacement in printing on packaging, found in metal coatings and more.

With a differentiated biopolymer-based micronized wax, the same rub resistance performance is achievable with a dosage reduction of 30 % – 50 %, making our additives a highly cost-efficient PTFE-alternative. Other benefits are:

- High mechanical and temperature resistance
- Low Coefficient of Friction (COF)
- Compliant with current and actually foreseeable regulatory requirements
- Improved sustainability profile
- Improved cost-performance effectiveness
- Fine texture in powder coatings

CLARIANT

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https://www.clariant.com/en/Business-Units/Additives-and-Adsorbents/Waxes/PTFE-Free-Solutions

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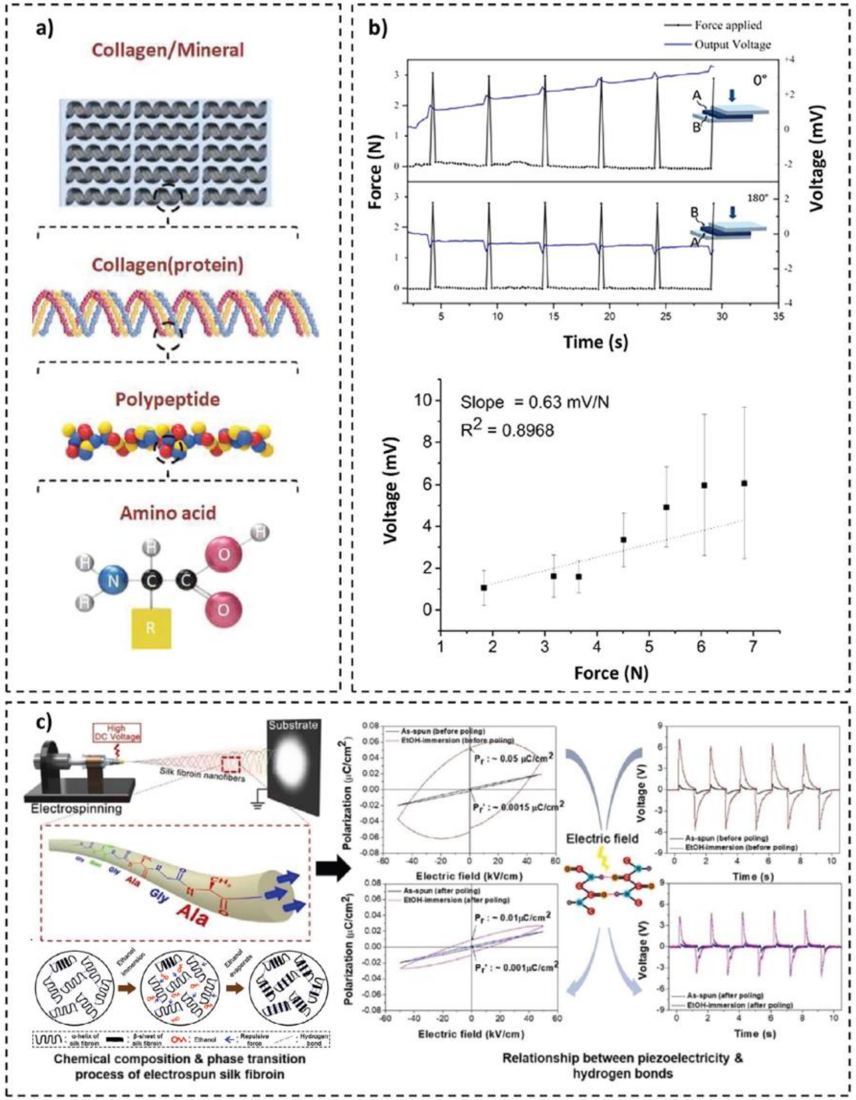
Alternatives to Fluoropolymers for Motion-Based Energy Harvesting: Perspectives on Piezoelectricity, Triboelectricity, Ferroelectrets, and Flexoelectricity

Peter C. Sherrell,* Anna Šutka, Martin Timusk,* and Andris Šutka Small 2024, 2311570

However, the performances quite low compared to PVDF and VDF Copolymers



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C. Sohn, H. Kim, J. Han, K.-T. Lee, A. Šutka, C. K. Jeong, *Nano Energy* **2022**, *103*, 107844.

Polymer	Piezoelectric co-efficient, d_{ij} [pC N^{-1}]			Refs.
	d_{33}	d_{31}	d_{14}	
PVDF	−24 to −34	8 to 22		[54, 55]
PVDF-TrFE	−25 to 40	12 to 25		[56–58]
PVDF-HFP	−24	30		[59, 60]
PLA		1.58	9.82	[61, 62]
Cellulose	5.7 ± 1.2	1.88 to 30.6	−35 to 60	[32-34, 43]
Polyamide 11	4	14		[63–65]
Polyurethane		27.2		[66]
Polyurea	19 to 21	10		[62, 67]
Polyimide	2.5 to 16.5			[43]
PAN		2		[68]

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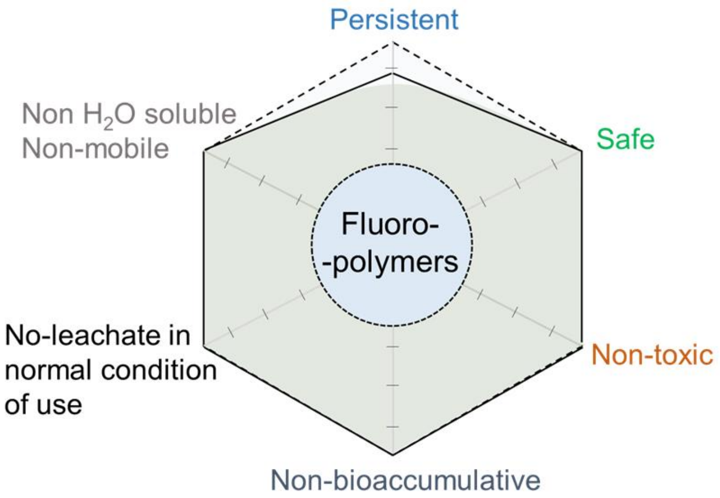
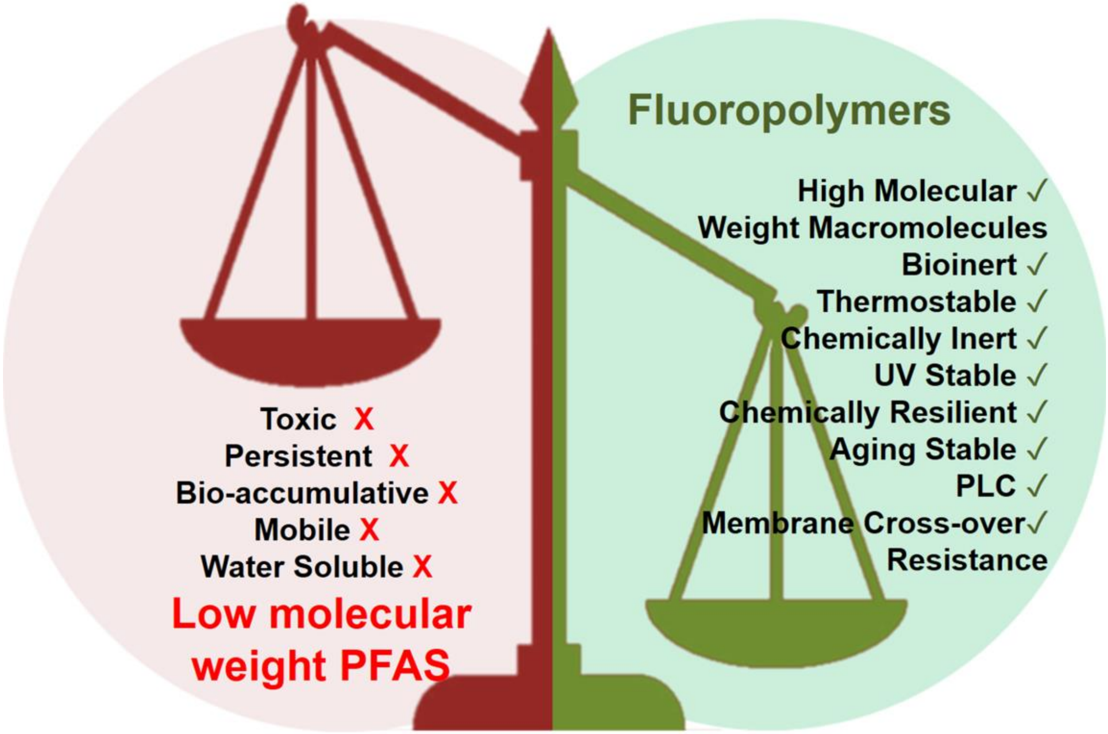
CONCLUSION

CHEMISTRY: MOLECU[...]IALS

- Still Surfactants Present all Over the Earth (From Decades of Productions & from A3F - Fires)
- F-Polymers: Niche Specialty Polymers with Exceptional Properties
- Fullfils the 13 PLC Criteria
- Innovating Processes of Production & Modification of Gas and Effluent Emissions
- So far, Few or No Alternatives





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PERSPECTIVES

CHEMISTRY: MOLECULES TO MATERIALS

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Restriction Dossier under Public Consultation on ECHA Portal Ended Sept. 25th, 2023

Led to > 5.600 Answers … 100,000 pages !!

THANKS

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Prof. Ph. Crouse (Univ. Pretoria, South Africa))
Dr G. Puts (Univ. Pretoria)
Dr M. Tramsek (Jožef Stephan Inst., Slovenia)

RECYCLAGE RECYCLABILITÉ RÉ-UTILISATION MATIÈRE PEPR

GIS - Fluor CNRS French Fluorine Network

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BE WELCOME !!

CHEMISTRY: MOLECULES TO MATERIALS

An ACS/POLY WORKSHOP

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How to Reduce Organic Fluorine in our Bodies?

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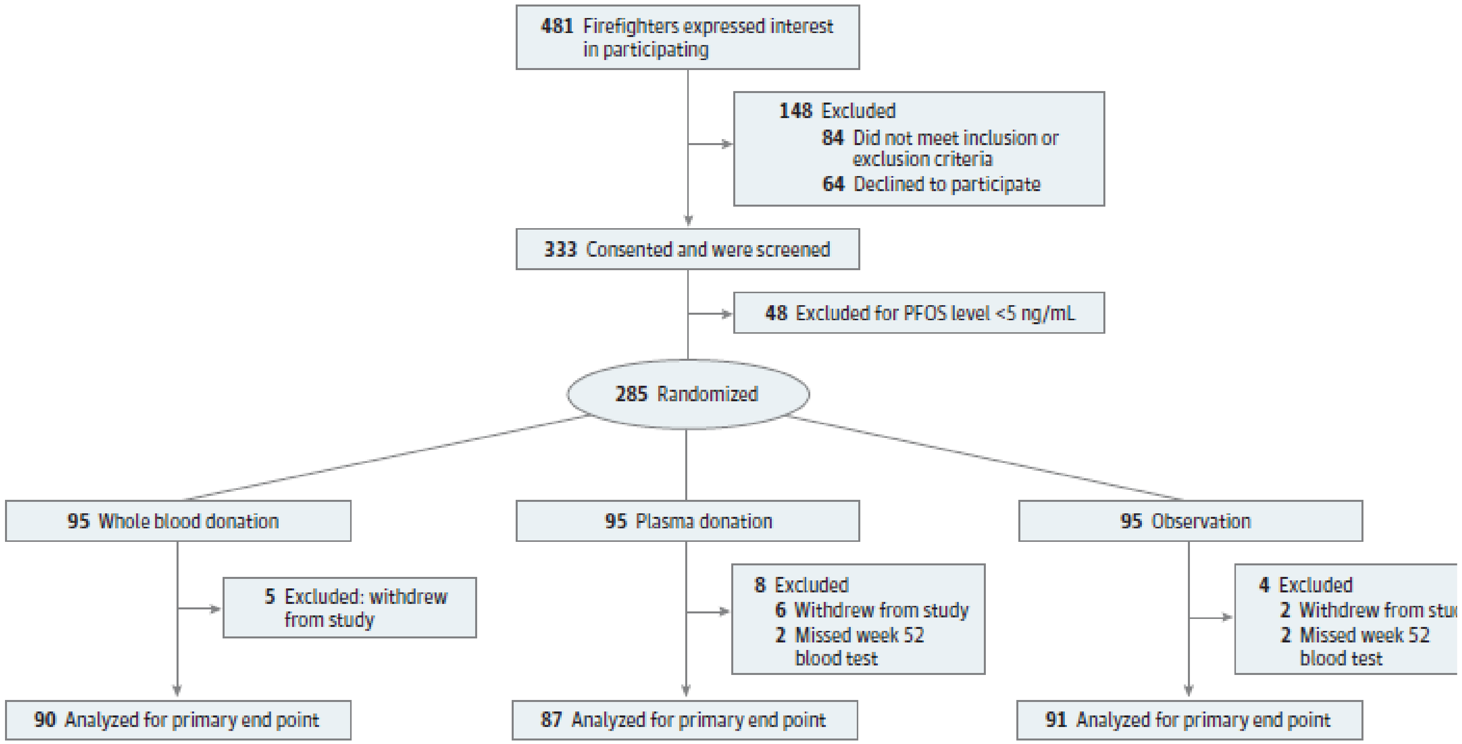

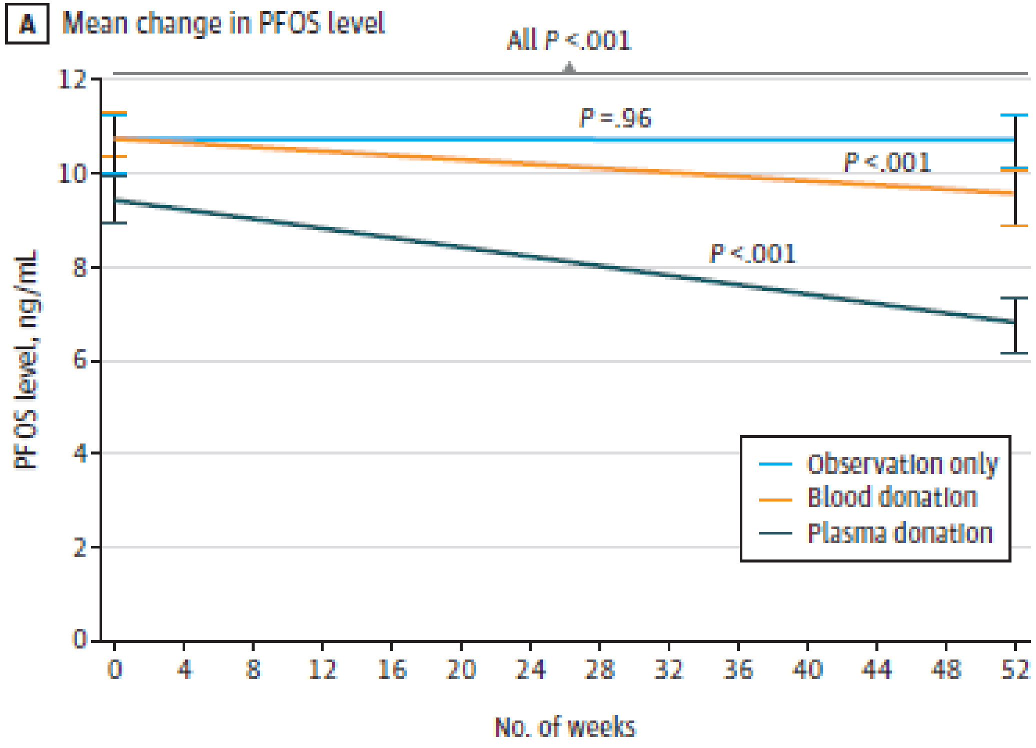

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