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PlasticsEurope Fluoropolymer Products
Group (FPG)

Socioeconomic Impact Assessment for fluoropolymers

FPG response to the PFAS draft restriction
proposal

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Acronyms and Abbreviations

Name	Description
AEMEL	Anionic exchange membrane electrolyzers
API	Active pharmaceutical ingredient
CfE	Call for Evidence
CSS	Chemicals Strategy for Sustainability
ECHA	European Chemicals Agency
ECTFE	Ethylene chlorotrifluoroethylene
EEA	European Economic Area (EU plus Norway, Iceland and Liechtenstein)
EPDM	Ethylene propylene diene terpolymer
ETFE	Ethylene tetrafluoroethylene
EV	Electric vehicles
e-VTOL	Electrical vertical take-off and landing
FCM	Food contact materials
FDA	Food and Drug Administration
FEPm	1-Propene, polymer with 1,1,2,2-tetrafluoroethene
FEVE	Fluoroethylene vinyl ether
FEP	Fluorinated ethylene propylene
FFF	Fire-fighting foams
FFKM	Copolymer of tetrafluoroethylene and perfluoromethylvinylether
FP	Fluoropolymers
FPG	Fluoropolymers Product Group of PlasticsEurope
GDL	Gas diffusion layer
HEPA	High-efficiency particulate air
HNBR	Hydrogenated nitrile butadiene rubber
IVD	<i>In vitro</i> diagnostics
LNG	Liquefied natural gas
MDD	Medical Devices Directive 76/764/EEC
MDI	Metered dose inhalers
MDR	Medical Devices Regulation (EU) 2017/745
MEA	Membrane electrode assemblies
NBR	Nitrile butadiene rubber
NPV	Net Present Value
OEM	Original Equipment Manufacturer
OPC	Open Public Consultation
PA	Polyamide
PAVE	Perfluoroalkyl vinyl ether
PCTFE	Polychlorotrifluoroethylene
PEEK	Polyether ether ketone
PEMEL	Proton exchange membrane electrolyzers
PEMFC	Proton exchange membrane fuel cells
PET	Polyethylene terephthalate
PFA	Perfluoroalkoxy polymer
PFAS	Per- and polyfluoroalkyl substances
PFCA	Perfluorocarboxylic acids

Name	Description
PFHxA	Undecafluorohexanoic acid
PFHxS	Perfluorohexane-1-sulphonic acid
PFOA	Perfluorooctanoic acid
PFPE	Perfluoropolyether
PP	Polypropylene
PPAP	Production part approval process
PPE	Personal protective equipment
PTFE	Polytetrafluoroethylene
PVC	Polyvinylchloride
PVDF	Polyvinylidene fluoride
SEA	Socioeconomic analysis
SOP	Start of production
TULAC	Textiles, upholstery, leather, apparel and carpets
VOC	Volatile organic compounds
XLPE	Cross-linked polyethylene

1. EXECUTIVE SUMMARY

- Value of fluoropolymers sold in the EEA in 2022 was €1.0 – 3.0 billion – expected to be €1.2 – 3.5 billion in 2025.
- Value of downstream markets using fluoropolymers was more than €700 billion in 2022 – can be more than €1 trillion in 2025.
- Proposed and considered derogations only cover an estimated 13-17% of fluoropolymer use in the EEA.
- NPV of loss for EU fluoropolymer industry in case of limited derogation for 2025-2030 period can be in the range of €6.2 – 18 billion.
- NPV of relevant downstream markets for the same period can be as high as €4.8 – 7.2 trillion.
- Fluoropolymers are key for all major industry sectors in the EEA, enabling key products and technologies for the functioning of the EEA society and economy and contributing to the EEA's climate change ambitions.

PlasticsEurope's fluoropolymer group (FPG) has prepared this report as part of their response to the open public consultation (OPC) for the PFAS restriction proposal. The aim of the report is to provide information on the socioeconomic benefits of the continued use of fluoropolymers in their applications across a broad range of industry sectors in the EEA.

The value of the fluoropolymers sold in the EEA in 2022 was estimated via an FPG member survey to be in the range of € 1.0 – 3.0 billion, and this number is expected to increase at a modest rate to approximately € 1.2 – 3.5 billion in 2025. Manufacturing in the EEA may decline, also following decisions from some manufacturers to stop production in the near future, but the overall demand is not expected to diminish, considering the importance of fluoropolymers for some major downstream industry sectors, including transportation (including electric vehicles), semiconductors and energy (including hydrogen and batteries).

The PFAS restriction proposal includes a large list of targeted, time-limited derogations for specific uses of PFAS and fluoropolymers. However, despite the number of applications and sectors considered for derogations, the vast majority of fluoropolymer uses are not covered by a proposed derogation, despite them being essential for many downstream manufacturing processes and products. For example, no derogation is envisaged at present in the restriction proposal for applications of fluoropolymers in the chemicals industry, in construction, and in potable water and wastewater treatment, while the proposed derogations for transport and energy applications would cover only a small share of the essential fluoropolymer applications. Overall, this report estimates that more than 80% of the fluoropolymer quantities sold in the EEA would not be covered by a currently proposed derogation and would potentially have to stop after the 18-month transitional period envisaged in the restriction proposal. This would mean that fluoropolymer manufacturing operations in the EEA will stop completely, as the volume covered by the proposed derogations would be too small to justify continued production, and the fluoropolymer production lines cannot easily be repurposed for different products. This could result in an overall loss of EU revenue in the range of € 6.2 – 18 billion for the 2025 – 2030 period, discounted to 2025 prices¹, along with the highly specialised and high value assets.

In case of a limited derogation scenario, in which the proposed derogations in the PFAS restriction proposal will remain as they are, the largest impact is expected to be felt by the downstream users that rely on the use of fluoropolymers for their processes and products. This report estimates that a market value of between € 700 and €1,400 billion in 2021 relied on the use of fluoropolymers in the EEA. In most, if not all, of these uses, fluoropolymers are necessary to achieve the desired product performance or process safety and reliability. It must be noted that the restriction would also prohibit imports of fluoropolymers for use in manufacturing processes, as well as in articles and equipment, such as vehicles, electronic equipment and medical devices.

¹ This assumes the EiF of the restriction in 2025.

It should be noted that the values presented above were calculated based on a number of assumptions and, in some cases, limited data, so can be considered as an indication of the size of the EU economy connected to the use of fluoropolymers rather than representing potential economic impacts in case fluoropolymers are subject to the derogation in the PFAS restriction proposal.

In any case, the benefits to the EEA society enabled by the use of fluoropolymers are manifold. Advanced technologies and products in medical devices, transportation, semiconductors and energy and electrical and electronic devices would not be possible without fluoropolymer components and coatings. In addition, critical (petro)chemical, pharmaceutical and other manufacturing processes can be operated safely and reliably thanks to fluoropolymer equipment, such as sealings, pipe linings, and filtering / separation membranes.

Fluoropolymers also enable the development of technologies that contribute to the EU's decarbonisation goals and circular economy, and the EU Green Deal. Technologies such as electric vehicles, smart electricity grids and hydrogen fuel cells would be pushed several years back if use of fluoropolymers is banned in the EU.

Overall, a scope-limited derogation scenario could result in significant impacts not just for the fluoropolymer manufacturers, but for the whole EEA economy and society. These critical functions of fluoropolymers should therefore be taken into consideration with an extended derogation for fluoropolymers.

2. BACKGROUND INFORMATION

2.1 Regulatory background on PFAS and fluoropolymers

On 14 October 2020, as part of the EU's zero pollution and circular economy ambitions (which in turn are key commitments of the European Green Deal), the European Commission published its Chemicals Strategy for Sustainability (CSS). The strategy contains several 'key actions', one of which is to phase out per- and polyfluoroalkyl substances (PFAS) in the EU, unless their use is proven essential to society².

More specifically, with regard to PFAS, the strategy highlights the following:

"Per- and polyfluoroalkyl substances (PFAS) require special attention, considering the large number of cases of contamination of soil and water - including drinking water - in the EU and globally, the number of people affected with a full spectrum of illnesses and the related societal and economic costs. That is why the Commission proposes a comprehensive set of actions to address the use of and contamination with PFAS. Those aim to ensure, in particular, that the use of PFAS is phased out in the EU, unless it is proven essential for society.

The Commission will:

- Ban all PFAS as a group in fire-fighting foams as well as in other uses, allowing their use only where they are essential for society;
- Address PFAS with a group approach, under relevant legislation on water, sustainable products, food, industrial emissions, and waste;
- Address PFAS concerns on a global scale through the relevant international fora and in bilateral policy dialogues with third countries;
- Establish an EU-wide approach and provide financial support under research and innovation programmes to identify and develop innovative methodologies for remediating PFAS contamination in the environment and in products;
- Provide research and innovation funding for safe innovations to substitute PFAS under Horizon Europe".³

A Commission Staff Working Document⁴ on PFAS accompanied the CSS. This further detailed the possibility for future regulatory initiatives concerning PFAS to address them as a group, primarily due to the prevalence of regrettable substitution as seen in the case of long-chain PFAS⁵.

Meanwhile, the EU has been actively working to restrict the manufacture, use and placing on the market of PFAS in the European Economic Area (EEA).

- Entry 68 of Annex XVII of REACH (Restriction List) restricts the manufacture, use and placing on the market of C9-C14 perfluorocarboxylic acids (PFCAs), including their salts and any combinations thereof above a certain concentration in the mixture or article. The restriction includes derogations until July 2025

² Note: there is as yet no formal definition from the Commission as to what constitutes Essential Use.

³ European Commission (2020a): Chemicals Strategy for Sustainability Towards a Toxic-Free Environment. Available at <https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf> (accessed 31 October 2022).

⁴ European Commission (2020b): Commission Staff Working Document on Poly- and perfluoroalkyl substances (PFAS). Available at <https://op.europa.eu/en/publication-detail/-/publication/2614f1f2-0f02-11eb-bc07-01aa75ed71a1/language-en> (accessed 31 October 2022).

⁵ As noted within the RfP "the EU has been regulating certain PFASs under the EU REACH Regulation as well as proposing regulation of the group of substances under the UN Stockholm Convention (Persistent Organic Pollutants). The most notable regulatory activity was to get PFOA, its salts and related substances ('C8 chemistry') under the EU REACH Restriction scheme. The industry moved on from 'C8 chemistry' to alternatives such as the so-called short-chain chemistry, incl. perfluorohexanoic acid (PFHxA), its salts and related substances ('C6 chemistry'). A REACH Restriction proposal for PFHxA and C9-C14 substances was submitted in late December 2019. ECHA's opinion was finalized in mid-2022."

for uses in semi-conductor manufacturing, photographic coatings in films, invasive and implantable medical devices and in some fire-fighting foams⁶. This restriction originally also included perfluorooctanoic acid (PFOA), its salts and PFOA-related substances, but the scope was narrowed down to C9-C14 acids after the inclusion of PFOA in Annex I (prohibition) of the POP Regulation in 2020.

- Perfluorohexane-1-sulphonic acid (PFHxS), its salts and related substances was also included in Annex IV (waste management provisions) of the POP Regulation in 2022.
- Undecafluorohexanoic acid (PFHxA), its salts and related substances are in the process of being restricted in the EU. The draft implementing act by the European Commission has a more limited scope than the original proposal, suggested specific restrictions, rather than a broad restriction with specific derogations⁷.
- PFAS in fire-fighting foams (FFF).

It must be noted that the restriction initiatives listed above are all very specific, in that they define a narrow scope, either by listing specific substances of known risk (PFCAs, PFHxA) or a well-defined application (FFF).

Nevertheless, at the time of publication of the CSS, the REACH competent authorities for Denmark, Germany, the Netherlands, Norway and Sweden had already initiated preliminary work on the (now published) broad (universal) restriction, covering all uses of a group of around 10,000 PFAS:

- A regulatory management option analysis conclusion document was published by the aforementioned authorities in June 2021⁸. The document concluded that *“a broad restriction under REACH covering all PFAS as a group would be the preferred option in order to limit as many (non-essential) uses as practically possible. This would have the greatest impact on minimising human and environmental exposure to PFAS, would also include currently unknown PFAS and uses, and would prevent regrettable substitution of restricted PFAS by other PFAS”*;
- The registry of restriction intentions until outcome was subsequently updated on 15 July 2021, with a scope for a *“restriction on manufacture, placing on the market and use of PFAS”*⁹;
- A consultation was held between 19 July 2021 and 17 October 2021¹⁰ whereby the authorities also presented multiple summary reports associated with EEA-based uses, tonnages and emissions. The purpose of the consultation was for stakeholders to check the presented data and provide feedback to support that the correct information is used for the assessment and preparation of the REACH Annex XV Restriction Dossier;
- Upon the submission of a formal restriction intention, the responsible competent authority has 12 months to submit its dossier to ECHA. However, the relevant authorities announced (in February 2022) a 6-month delay in submission, with an updated expected date of submission to ECHA of 13 January 2023; and
- On February 7, 2023, ECHA pre-published the full restriction report for the EU REACH restriction proposal, which aims to ban the uses of more than 10,000 PFAS.
- On March 22, 2023, ECHA formally published the Annex XV report for the EU REACH restriction proposal and kicked off the six-month open public consultation (closing on 25 September 2023), giving all stakeholders the opportunity to submit information on their PFAS uses and the availability of alternatives.

The universal PFAS restriction proposal focuses on the manufacture, placing on the market and use of PFAS, including polymeric PFAS (fluoropolymers). The restriction proposal defines PFAS as *“Any substance that*

⁶ See <https://echa.europa.eu/documents/10162/f9e7b269-87cd-fc26-1a8e-b8c8b6e40c08>

⁷ See <https://ec.europa.eu/transparency/comitology-register/screen/documents/090483/1/consult?lang=en>

⁸ See <https://echa.europa.eu/documents/10162/a59647fb-fcc5-869b-10d4-c14258bbea1d>.

⁹ See <https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b>.

¹⁰ See https://www.reach-clp-biozid-helpdesk.de/SharedDocs/Downloads/DE/REACH/Verfahren/Beschr%C3%A4nkung/Consultation-PFAS.pdf?__blob=publicationFile&v=1.

contains at least one fully fluorinated methyl (CF₃-) or methylene (-CF₂-) carbon atom (without any H/Cl/Br/I attached to it).”, though there are exceptions.

The scope of the proposed ban includes all uses of PFAS, regardless of whether they are specifically assessed or mentioned in the restriction proposal, unless a specific derogation applies. Figure 2.1 below reproduces Table A.1 from Annex A to the restriction proposal, which lists the PFAS applications and the level of scrutiny they received in the restriction proposal development process¹¹.

PFAS applications			
PFAS manufacture	Textile, upholstery, leather, apparel and carpets (TULAC)	Food contact materials and packaging	Metal plating and manufacture of metal products
Consumer mixtures	Cosmetics	Ski wax	Applications of fluorinated gases
Medical devices	Transport	Electronics and semiconductors	Energy sector
Construction products	Lubricants	Petroleum and mining	Waste stage PFAS applications
Laboratory equipment & filtration	Plant protection products and biocides	Chemical industry	Firefighting foam
Medicinal products	Plastics (other than packaging) and rubber/elastomer production (including flame retardants)	Pyrotechnics	Personal care products other than cosmetics
Fracking (currently hardly applicable in EEA)	Immersion cooling (currently hardly applicable in EEA)	Defence industry	Printing inks
Cement industry	Professional cleaning and polishing	Other niche applications	Uses (yet) unknown

- Green uses are researched in detail
- Blue uses are researched in general
- Orange uses not researched in detail
- Purple use: Separate restriction proposal

Figure 2.1 Overview of PFAS applications and the level at which they were researched (reproduced from Annex A to the PFAS restriction proposal)

The restriction proposal includes a number of proposed derogations and derogations subject to reconsideration. These are for most of the uses and applications of PFAS that were researched in detail. The broadness of their scope varies, from very specific single applications to broader sectors (e.g., for petroleum and mining industries).

2.2 Aim of the report

The Fluoropolymers Product Group of PlasticsEurope (FPG) is participating in the public consultation on the proposal for a restriction of PFAS, which was initiated by ECHA and runs until 25 September 2023. As part of their response, FPG wants to present relevant data on the uses / applications of fluoropolymers in the EU, including information on tonnages of fluoropolymers used, the availability of suitable alternatives, and the socioeconomic benefits of the continued use of fluoropolymers for the EU society. The input of FPG is being submitted in two separate reports.

This is the second of two reports submitted by FPG. In the first response, which was submitted to the open public consultation on 07 July 2023, with comment number 6150, the aim was to highlight the broad range of

¹¹ Annex A to the Annex XV Restriction report for Per- and poly-fluoroalkyl substances. Available online at: <https://echa.europa.eu/documents/10162/f71f3bed-e48d-5004-d195-e293c38d0602>, accessed on 29 May 2023

fluoropolymer uses in the EU and the difficulty in identifying and implementing suitable alternatives for most of these uses. The summary from that report can be found in Chapter 3 of this report, for reference.

This report aims to provide a high-level overview of the importance of fluoropolymers for EEA society and economy and the potential socioeconomic impacts of the proposed restriction and it complements the first one. Where relevant, references are made to relevant sections of the first report.

2.3 Scope of the report

The restriction proposal defines PFAS as “Any substance that contains at least one fully fluorinated methyl (CF₃-) or methylene (-CF₂-) carbon atom (without any H/Cl/Br/I attached to it).”¹² There are many families of polymeric PFAS (fluoropolymers) manufactured and used in the EU as compounds or as fully formed articles. They can be largely grouped under fluoroplastics such as PTFE and fluorinated elastomers, while perfluoropolyethers is another family of FP with wide use.

As part of the public consultation, ECHA is requesting any data that could help them and the dossier submitters to inform their opinions and amend the restriction proposal. There are also more specific information requests, including:

1. Emissions in the end-of-life phase.
2. Impacts on the recycling industry.
3. Tonnage and emissions for the proposed derogations.
4. Information on alternatives, substitution potential and timelines, and socioeconomic impacts of non-use for uses that are not examined in detail in the restriction proposal.
5. Information on alternatives, substitution potential and socioeconomic impacts of non-use for the potential derogations that are marked for reconsideration.
6. Similar information as items 3 and 4 for any other use of PFAS, including fluoropolymers.
7. Degradation potential of specific PFAS groups

This report will mainly focus on points 4-6 above, and more specifically on outlining the diverse societal benefits enabled by the use of fluoropolymers in sectors of the EEA economy as well as their huge economic significance.

The geographic scope of this document will be the EEA, the area where the PFAS restriction will apply. The report will apply to fluoropolymers manufactured, imported and used in the EU, either as such, in mixtures or in/on articles, by the members of FPG that participated in the provision of information.

An extensive stakeholder survey, covering the FPG member companies participating in the study and downstream users of fluoropolymers in the EEA was undertaken in February and March 2023. The FPG consultant prepared two questionnaires, one for FPG members and one for downstream stakeholders. The questionnaires included questions on the uses of fluoropolymers, their function, assessment of potential alternatives and the socioeconomic impacts in case no derogation was granted for uses. The survey received a total of 144 responses, eight from FPG members and the remaining 136 from downstream stakeholders. The responses were collated and the aggregated relevant information is included in this report.

¹² Annex XV Restriction report – Proposal for a submission: Per- and polyfluoroalkyl substances (PFASs). Available online at: <https://echa.europa.eu/documents/10162/f605d4b5-7c17-7414-8823-b49b9fd43aea>, accessed on 07 September 2023

3. SUMMARY FROM PREVIOUS REPORT ON ALTERNATIVES AND SUBSTITUTION POTENTIAL

3.1 Background information on the report on uses and alternatives (Previously submitted report)

On March 22, 2023, ECHA formally published the Annex XV report for the EU REACH PFAS restriction proposal and kicked off the six-month open public consultation giving all stakeholders the opportunity to submit information on their PFAS uses and the availability of alternatives. The public consultation is going to last until 25 September 2023.

The Fluoropolymers Product Group of PlasticsEurope (FPG) prepared the first report for submission to the public consultation on the proposal for a restriction of PFAS, by providing relevant data on the uses / applications of fluoropolymers in the EU, including information on tonnages of fluoropolymers used, and the availability of suitable alternatives. Within the first report, the aim was to highlight the broad range of fluoropolymer uses in the EU.

The information presented in the first report was collected via literature review of publicly available sources and through an extensive survey with FPG member companies, i.e., the fluoropolymer manufacturers, and downstream users of fluoropolymers, which received responses from over 130 companies in total.

3.2 Applications of fluoropolymers

Fluoropolymers are a versatile and durable group of materials, which are used in a very broad range of industry sectors, primarily for professional and industrial applications. They can be grouped in three main categories, namely fluoroplastics (PTFE, ETFE, PVDF, PFA, etc.), fluorinated elastomers (FFKM, etc.), and specialty fluoropolymers (PFPE as lubricant, amorphous fluoropolymers, fluorinated ionomers).

Fluoropolymers exhibit a combination of properties that make them the only suitable material for a broad range of applications, where durability to extreme temperatures, aggressive chemical agents and mechanical stress is essential, together with oil- and water-resistance, non-stick properties and / or low coefficient of friction. As a result, they are often the only type of materials suitable for use in applications where such harsh, extreme conditions are expected to be present.

Their versatility allows them to be used in different forms, such as:

- Coatings to protect a substrate from water, oil, chemicals or UV radiation, or to offer a low-friction surface in construction and transportation.
- Moulded sealing components to prevent leakage of hazardous or infectious agents in processes.
- Filter membranes, ensuring removal of all potential contamination in ultraclean manufacturing environments (e.g., in semiconductor manufacturing) or in the treatment of drinking water and wastewater.
- Ion-exchange membranes that are used in electrochemical processes, in the chemical industry and for power generation (e.g., fuel cells, hydrogen generation).
- Lubricants or lubricant additives in very demanding transport and industrial applications.

According to information provided by FPG members, in 2022 the quantities of fluoropolymers manufactured or imported in the EU were in the range of 40,000 – 95,000 tonnes. This indicates an increase to the volumes declared for 2020 in a previous SEA document on fluoropolymers, but it is within the range of fluoropolymer usage assumed in the PFAS restriction proposal. Transport (road, off-road and aerospace) applications accounted for the highest usage of fluoropolymers, followed by the chemical processing industry. Other critical sectors of fluoropolymer applications are energy (including power generation, Li-ion batteries, and hydrogen technologies), electronics and semiconductors, food processing (food contact and processing materials, cooking surfaces, packaging), medical devices, petroleum and mining, military and defence, technical and non-technical textiles, and water and wastewater treatment.

3.3 Analysis of alternatives

The fields of application for fluoropolymers are variable, but one common parameter is that fluoropolymers are chosen due to their superior performance in applications where other solutions are not available or would have significantly worse performance, leading to significant safety concerns, and need for more frequent maintenance or replacement due to failures. In some cases, such reduced performance would not be accepted by the final users of an article or the operators of a process.

Many of the fluoropolymer applications are in sectors that are governed by strict industry standards and regulatory processes, to ensure a high level of safety and performance, for the benefit and protection of the public. Such sectors are aerospace and transportation, construction, medical devices, electronics, food processing, and water and wastewater treatment.

Other manufacturing processes also need to ensure a high level of cleanliness and / or safety for both the workplace and the environment. For example, the chemical processing sector needs to prevent leakage of hazardous chemicals from transfer and processing equipment, such as piping, vessels, pumps and valves. Fluoropolymer linings, coatings and seals are often the only suitable option. Furthermore, semiconductor, pharmaceutical, medical device and some fine chemical manufacturing processes need very clean environments, which can only be achieved through the use of fluoropolymer coatings or membranes in filters. Fluoropolymer lubricants are also used in a broad range of applications where harsh conditions are expected and other materials cannot meet the performance and safety requirements.

In this broad range of applications, fluoropolymers are the material of choice, and, in many cases, required by the industry standards. Alternative materials cannot provide the combination of properties exhibited by fluoropolymers, as they cannot display the required resistance to a wide range of temperatures, and degrade in presence of aggressive chemicals (e.g., petroleum products, caustic chemicals) or other contamination.

It must also be noted that fluoropolymers are usually more expensive than the potential alternative materials. The fact that they are preferred over cheaper materials, especially in some very cost-sensitive industries, such as chemical processing and transportation, is a strong indication that the potential alternatives are not suitable for the particular uses.

3.4 Conclusion

Overall, fluoropolymers are materials with a unique combination of properties that are used in a broad range of applications where harsh conditions are expected. They are critical for the safe use of equipment and for maintaining ultra clean manufacturing and operating environments, with no leakage or contamination over very long lifespans. Their continued use in those applications is necessary, as they are outperforming alternatives and should a potential alternative be identified, substitution may not be feasible without several years of testing and qualification.

While work on substitution is ongoing, and potential alternatives have been identified for some applications, it is unlikely that it will be possible to replace fluoropolymers in all applications in which they are currently used and certainly not within the time frames envisaged by the PFAS restriction proposal. The demanding specifications in these sectors mean that substitution will be achieved only through a long, structured process, and via rigorous testing. Considering the current status of alternatives and the unique combination of properties exhibited by fluoropolymers in demanding applications, where safety and performance are a priority, it is very likely that fluoropolymers will need to continue being used for more than 10 to 15 years.

Table 3.1 Summary of fluoropolymer applications, status of alternatives, and substitution potential

Application	Indicative uses	Fluoropolymers used (not exhaustive)	Status of alternatives	Substitution potential
Transport, including automotive and aerospace	Fuel tubing and hose, engine oil and drivetrain seals (O-rings, gaskets), O-rings, seals, gaskets, ice-phobic coatings on helicopter rotor blades, window shades Exhaust gas pipes. Fuel cell membranes Oxygen, NO_x sensors, emission control systems. Pedal, battery, oil, radar, rain-light sensors Transmissions seals, thermal management systems Transfer or compression moulded automotive fuel Wires and cables Signal, control and power wires and cables insulated with fluoropolymers in military and civil aviation. Foams in aircraft insulation Electroluminescent lamps	Poly(TFE-ter-VDF-ter-PMVE), Poly(TFE-ter-PMVE-ter-VDF), Copolymers of tetrafluoroethylene and propylene, FKM, FFKM, PVDF, PTFE, ETFE, FEP	Technical requirements and OEM specifications do not allow use of alternatives in harsh conditions (e.g., temperatures above 200°C, exposure to oils and fuel). Alternative rubbers cannot meet resistance to broad range of temperatures and to chemical agents in applications such as cable jacketing (for power transfer and sensors) and sealing.	The extreme performance requirements and specifications, combined with long qualification and certification processes make substitution of fluoropolymers in transport applications extremely difficult. Alternative development and qualification, process validation and certification and subsequent scale up and commercialisation of the alternative can be as long as 10 – 15 years or even longer in some cases (e.g., in aviation applications), even considering that a potential alternative has been identified.
Chemical processing	Fluid handling systems, Pipes (solid pipes and pipe linings), flue duct expansion joints. Seals, gaskets, valves, fittings, linings, filters, O-rings. PTFE-thread sealing tape. Tanks, lining of reaction vessels. Ion-exchange membranes (e.g., for chloralkali production). Wire and cable coatings for sensors, flowmeter tubes, and other electrical and electronic sensing and control equipment. Extrusion and moulding aids.	PTFE, FEP, PFA, ECTFE, EFPM, PVDF, fluorinated ionomers (ion exchange membranes), ETFE, FKM, and FFKM	Sealing from alternative rubbers cannot meet performance requirements for temperature (-40°C to 270°C), gas and chemical resistance. Chemical resistance is a main criterion, as alternative materials in pump, piping, etc. components cannot handle aggressive chemicals. Broad temperature compatibility is also essential for applications in flexible hoses and cryogenic media seals. These requirements	Alternative materials used in chemical processing cannot meet the high stability and performance requirements in chemical processes. In addition, any change in material requires long R&D, qualification, validation and commercialisation procedures before a suitable alternative is Industry stakeholders expect that such procedures can take several years, depending on the application, provided that a

Application	Indicative uses	Fluoropolymers used (not exhaustive)	Status of alternatives	Substitution potential
			can only be met by fluoropolymers. The alternatives to PEM cells in the essential chloralkali manufacturing industry use very hazardous materials (asbestos and mercury) and are also less energy efficient than membrane cells.	suitable alternative has been identified.
Construction	Wire & cable insulation, plenum cable insulation, Architectural protective and decorative coatings (e.g., on bridges), laminates, resistant paints, anti-graffiti and antifouling coatings, surface treatment in natural stone, metal, glass, plastic Bridge and offshore pad bearings Greenhouse films PTFE-thread seal tapes for pipes	PTFE, PVDF, PEF, PFA, ETFE	Potential alternatives in construction and architectural applications have worse performance (In plenum application fire safety performance can be unacceptable) than fluoropolymers and would be unsuitable where harsh conditions (environmental, mechanical) are expected. Alternative agricultural coatings have lower durability than fluoropolymers, which would require more frequent re-coating or replacements, with higher environmental load.	Substitution for construction and architectural applications, including PTFE-thread seal tapes depends heavily on stability testing over several years (6 to 12).
Energy, batteries and hydrogen	Solar panel coatings, O-rings, seals, gaskets, proton exchange membranes in fuel cells, in alkaline electrolyzers and for hydrogen production via electrolysis, binder materials in the electrodes, both anode and cathode, and as a component of the gas diffusion layers (GDLs).	PVDF, Poly(TFE-ter-PMVE-ter-VDF), PTFE, ETFE, FKM, FFKM, other fluorinated elastomers, FEP	Some low energy alternatives for batteries are available, but they are not suitable for all applications, especially those that have space limitations, such as in transportation. In general, for Li-ion battery binders, the potential alternatives will require further testing and	The limited suitability of potential alternatives (due to durability and performance) for these applications and the long R&D and qualification procedures make substitution of fluoropolymers very difficult. For hydrogen applications (e.g., electrolysis membranes),

Application	Indicative uses	Fluoropolymers used (not exhaustive)	Status of alternatives	Substitution potential
	Infrastructure for transport and storage of hydrogen (lining materials, seals etc.), seals in liquid organic hydrogen carrier technologies. Potentially in turbines in flanged connections in order to mitigate leakages, in power generation using H₂. Binders in electrodes of batteries, separator coatings, additives in the electrolyte, gaskets/seals, pipes, valves and sealings in the battery itself, manufacturing of positive electrodes for Li-ion cells Solar panel and wind turbine blade coatings.		development before they can meet the performance requirements. For ion-exchange and electrolysis membranes used in hydrogen production, non-fluorinated alternatives still have worse durability and much shorter lifetimes than fluoropolymers. Sealing and cable jacketing alternative materials have lower resistance to temperature and chemicals than fluoropolymers, which make them unsuitable for use in applications with harsh conditions present.	alternatives may not be available for the next 10 years at least. For other applications, which also depend on meeting high performance requirements, substitution can also take many years.
Petroleum and mining	Chemical resistant components (e.g., seals) and coatings for extraction, transport and processing of petroleum and ores. Wire and cable insulation and covering Coating for sensors	FEP, PVDF, FKM, FFKM, FEP, PFA	Alternatives for applications in the petroleum and mining sector cannot meet the very high performance requirements for temperature (as high as 270°C), chemical and mechanical resistance. This appears to be recognised by the restriction proposal dossier submitters, who proposed a derogation for such uses. However, these performance requirements also extend to transport and processing of these chemicals and ores, with very extreme conditions often present.	The extreme performance requirements and specifications, combined with long R&D and qualification make substitution of fluoropolymers in petroleum and mining applications extremely difficult. Stakeholders expect that substitution can take as long as 10 years, provided that an alternative is available, which is not the case.
Food contact materials and packaging	Industrial, commercial and consumer cookware and bakeware	PTFE, PPPE, FEPM, PVDF, PFA	Alternative materials for cook- and bakeware do not have the combination of properties that	Food contact materials are heavily regulated and any FCM must

Application	Indicative uses	Fluoropolymers used (not exhaustive)	Status of alternatives	Substitution potential
	Water and oil-repellent coating on paper products and packaging (cans, bags, etc.) Conveyor belts for cooking and drying foodstuff Processing / polymerisation aids for plastic film production Process lubricants		fluoropolymers offer and may fail in durability, non-stick, and temperature, chemical and abrasion resistance. In addition, no suitable alternatives are available in the EU for processing aids.	meet several quality and safety standards. Any change would include identifying an approved FCM and running a series of durability and migration tests. The overall process can take at least three years, provided that the selected alternative is successful at all stages. High performance and safety requirements for FCM and the current status of alternatives means that substitution would take significant longer than that.
Electronics and semiconductors	Components of electronic devices (e.g., Hard disk drives), Semiconductor manufacturing (e.g., HEPA filters, wet processing equipment components) O-rings, seals, gaskets, parts and tubing used in the semiconductor processing industry, Welding and soldering agent, Insulation in wires and cables, Coatings, batteries and smart devices Powder coating for phone and tablet screens. Anti-reflective coatings for semiconductors Sensor applications (industrial, automotive, measuring and analytical)	PVDF, PFA, PFPE, PTFE FKM, FFKM, ECTFE, FEP	Alternatives for electronics and semiconductor applications cannot fulfil the temperature and chemical resistance required. The semiconductor industry in particular requires ultra-high purity and thermal resistance, which cannot be met by alternatives. Non-fluoropolymer alternatives are likely to cause contamination to products. Alternatives do not have the combination of properties offered by fluoropolymers and fail in temperature, chemical or mechanical resistance requirements. Analytical instruments and sensors also require high precision and cleanliness, and	The lack of alternatives for semiconductor applications, together with long R&D and qualification procedures make substitution in these applications extremely difficult. It can take as long as 10-15 years to develop an alternative to fluoropolymers, assuming that a suitable alternative is identified and there are no setbacks during the qualification and verification. Electronic equipment also has to carry out lengthy verification and validation testing to meet the very high performance and safety requirements by customers. This process can also take several years, especially considering that for many applications there are no alternatives.

Application	Indicative uses	Fluoropolymers used (not exhaustive)	Status of alternatives	Substitution potential
			only fluoropolymers can offer the required level of purity.	In addition, some products (e.g., cables and other electrical / electronic equipment) may need to receive third party approvals for CE Mark or other certifications by independent third parties, which is a process that can take several years, subject to the third party's availability.
Water and wastewater treatment	Hollow fibre micro- and ultra-filtration water & wastewater treatment membranes Water piping	PTFE, PVDF	Experience with other materials such as polyether sulfone or chlorinated polyethylene have shown that the lack of flexibility, cleanliness and chemical resistance result in short life expectancy and high operating cost for municipal and industrial users. Such materials may be in use for some low risk applications, but not for water with high levels of contamination such as surface water, urban WWTTP and industrial wastewater. Fluoropolymers enable these waters to be used or reused for drinking water, utility water, process water or irrigation	Potential alternatives are not suitable for demanding water and wastewater applications where high levels of contamination are present and any substitution could take several years (as long as 5-10, but most likely over 15). Substitution is made even more difficult as the alternatives would require more space, which is not possible for most current installations, and many more frequent replacements.
Lubricants	High performance Lubricants (stable and inert) for applications in the aerospace, military, automotive, electronics, semiconductor, textile, chemical, paper, plastic and nuclear industries. Also in wind turbines as, due	PPPE, PTFE	Ceramic based membranes are not suitable for large scale water and wastewater applications with space constraints. Alternatives cannot meet the high performance requirements in the various applications (automotive, chemical processing industry, food processing, drinking water treatment), as they have worse	Lack of high-performance alternatives for most applications makes substitution difficult. Furthermore, qualification and testing requirements for each

Application	Indicative uses	Fluoropolymers used (not exhaustive)	Status of alternatives	Substitution potential
	to their inaccessibility, they cannot be serviced regularly. High performance lubricants for engines and machinery. Lubrication for vacuum pumps, high-pressure oxygen equipment. Non-stick coatings as dry film lubricants in baked goods production, food processing, automotive and transportation, high-temperature kitchen equipment, medical equipment.		durability against chemicals and temperature and are dependent on the temperature, which is not the case for fluoropolymer-based lubricants.	application can take several years, depending on the industry sector.
Medical devices and pharmaceuticals	Biomedical devices Other medical devices, e.g., catheters, stents, heart patches, sutures, seals, lubricants, filters or surface treatment Coating in primary packaging components, coating for metered dose inhalers Analytical equipment and laboratory applications.	PTFE, ETFE, PVDF, FEP, FKM, PFA	Alternatives do not have the combination of thermal, chemical and mechanical resistance, together with the biocompatibility, offered by fluoropolymers. Particularly for cables used in medical equipment and in invasive procedures (e.g., endoscopy, surgeries), alternative rubbers are not conducive to the miniaturised equipment needed to perform them (e.g., endoscopy cables, guiding wires). Sealing and filtering equipment, relevant to the sensitive and low contamination tolerant manufacturing processes in these sectors, also do not have suitable alternatives, as discussed in sections on semiconductors, chemical processing, and petroleum and mining.	Medical devices and pharmaceuticals are heavily regulated products and any change in the product or the manufacturing process must undergo lengthy testing and qualification procedures and receive approval and certification from competent third parties. These processes could take 10-15 years to develop an alternative to fluoropolymers, but that could depend on the application, and on no unacceptable results during validation and approval.
TULAC	Waterproof and stain repellent clothing	PTFE	Alternatives for filtering media cannot meet the performance	Substitution in demanding applications may not be possible

Application	Indicative uses	Fluoropolymers used (not exhaustive)	Status of alternatives	Substitution potential
	Chemical resistant PPE, fabrics, and high-performance textiles Membranes used as filtering media in applications with very low contamination tolerance (e.g., semi-conductors, pharmaceuticals, medical devices, chemical processing) Coated fabrics for architectural applications, tents and furniture		and safety requirements, as discussed in other applications (e.g., semiconductors, chemical industry). Alternatives do not appear to be available for more demanding applications (e.g., heavy rain resistance or dynamic water repellence, and high alcohol repellence needed in medical uses), where only the superior performance of fluoropolymers is suitable.	in the short term, due to non-availability of suitable alternatives. For some applications, e.g., in pharmaceutical and medical devices, this can take much longer, as explained in the relevant section.
Metal plating and manufacturing of metal products	Noise suppression, anti-foam agent Electrical insulation and sealing in metal heating processes. Noise reduction and as dry bearings in metal product manufacturing processes.	PTFE	As per the information in the annexes to the restriction proposal, there is limited information available on alternatives for hard chrome plating.	Substitution activities for such applications would relate to the end product, which could be used in the transport, chemical, etc. sectors. Considering the discussion for the relevant applications, substitution of fluoropolymers in hard chrome plating applications can be long.
Cosmetics, consumer mixtures, ski wax and other uses	Polishes and waxes for stone surfaces for consumers and professionals Cosmetic applications (dental floss, perfume dip tips) Ski waxes	PTFE, FFKM	The dossier submitters mentioned strong evidence for the presence of technically feasible alternatives for consumer mixtures (e.g., for cleaning mixtures, waxes and polishes, dishwashing products, windscreen fluids for cars, and guitar strings), cosmetics and ski waxes. The stakeholder survey carried out for this report did not produce any additional information.	Considering the status of alternatives for these uses, as identified in the annexes to the restriction proposal, it is expected that substitution will be possible for most, if not all the applications.

4. SOCIOECONOMIC IMPACT ASSESSMENT

4.1 Market summary

The fluoropolymer market in 2020 has been described in a previous SEA document, which was submitted during the earlier Call for Evidence and is also available at the FPG website¹³.

That SEA includes two tables breaking down the usage and value of fluoropolymers across the different market sectors. The previous SEA document presented two breakdowns by sector, the first to match an earlier report from 2016-17 and the second one to match the studies that were supporting the PFAS restriction proposal in 2020. These tables are reproduced below.

Table 4.1 Sales of fluoropolymers in the EU in 2020 per sector of use, as per 2016-17 report (reproduced from Table 3.6 of previous FPG SEA)

Sector of use	Total quantities sold (t)	Total value (€ million)
Chemical and power	11,000	220
Food and pharmaceutical industry	2,000	30
Electronics	3,500	70
Transport	15,500	280
Renewable energy	500	20
Cookware	2,000	30
Medical applications	500	20
Textiles and architecture	1,500	40
Other sectors	3,000	60
Total	40,000	740

Table 4.2 Sales of fluoropolymers in the EU in 2020 per sector of use, as per sector breakdown in studies supporting PFAS proposal (reproduced from Table 3.7 of previous FPG SEA)

Sector of use	Total quantities sold (t)	Total value (€ million)
Chrome plating	0	0
Consumer mixtures	1,000	10
Cosmetics	Confidential	Confidential
Construction	4,500	90
Electronics	4,000	80
F-gases	0	0
Firefighting foams	0	0
Food contact materials	3,000	50
Lubricants	1,500	30
Medical devices	500	20
Petroleum	3,500	70
Mining	Confidential	Confidential
Ski wax	Confidential	Confidential
Textiles	500	10
Transportation	16,000	280
Other sectors	5,500	120
Total	40,000	740

The total usage of fluoropolymers in the EU (manufactured and imported) in 2020 was estimated at approximately 40,000 tons per year, and the value of the products at approximately € 750 million. Fluoropolymer sales exhibited a downward trend compared to 2015. The restriction proposal estimated the total volume of PFAS placed on the market in 2020 at between 72,000 and 185,000 tons. It is understood that these numbers also include side-chain fluorinated polymers.

¹³ Wood (2022). Update of market data for the socioeconomic analysis (SEA) of the European fluoropolymer industry. Available online at: https://fluoropolymers.plasticseurope.org/application/files/1216/5485/3500/Fluoropolymers_Market_Data_Update_-_Final_report_-_May_2022.pdf, accessed on 21 August 2023

It should be noted that Table 4.2 does not include a chemical industry sector breakdown, but it is understood that the quantities presented in Table 4.1 are distributed in the different sectors, most likely in the “other sectors” category.

As part of this 2023 report, an attempt was made to update these numbers with more recent data collected by FPG member companies. The updated volumes are collected in Table 3-2 of the previously submitted report to the OPC and were estimated at between 40,000 and 95,000 tons in 2022. The updated estimated revenue from fluoropolymers in 2022 resulted in a much higher number of approximately € 1 – 3 billion, as shown in Table 4.3.

Table 4.3 Value of fluoropolymers sold in the EU in 2022 per sector of use

Sector of use	Fluoropolymers sold in EU in 2022 (in € million)	Future market trends forecasts
Transportation and aerospace (excluding lubricants)	250 – 500	The demand from the transportation (land and aerospace) sector is expected to remain strong in the future, with the overall market showing slow but sustained growth. This trend is supported by the increased demand for EVs and the emergence of zero emission technologies such as hydrogen fuel cells in commercial vehicles. The hydrogen industry is expected to have a strong influence on fluoropolymer demand, as discussed in the energy applications section. Dossier submitters have assumed a growth rate of approximately 1%, which seems low, considering the increasing demand for electric vehicles and hydrogen fuel cells.
Industrial applications (chemical industry, excl. lubricants)	100 – 250	FPG members expect a slow but steady growth in the demand for fluoropolymers in the chemical processing industry. The demand is expected to be stronger for specific sectors that rely extensively on fluoropolymers, such as the chloralkali sector, which requires fluorinated ionomer membranes. Dossier submitters have not considered at all this very important market sector in the restriction proposal. For calculation purposes, a modest growth of 2% is assumed in this report.
Construction materials and products	100 – 250	FPG members expect the construction market for fluoropolymers to grow in the short- and long-term. The forecasted growth can be attributed to the overall construction sector growth as well as to expected increased demand for protective coatings. An annual growth rate of 5-10%, at least in the short-term is expected. The dossier submitters assumed a strong growth until 2030, with a slowdown in the years after that (2.5% until 2040 and 1% afterwards).
Energy applications, including batteries and hydrogen	150 – 500	The demand for fluoropolymers for energy applications is expected to grow significantly in the short- and long-term, stimulated by the EU's electrification and decarbonisation targets for 2030 and 2050. Market segments that are expected to drive this growth are electrolysis installations for green hydrogen production, photovoltaic sheet coating, and fuel cell PEM. In addition, use of fluoropolymers as binders in batteries is also expected to increase due to the increased need for storage capacity and EV demand. The overall growth is expected to be significant. Dossier submitters have assumed a 10% growth increase for energy uses in the EU, particularly as a result of the EU's Green Deal and decarbonisation goals. The hydrogen targets (40GW electrolysis capacity by 2030) is among the main drivers for this trend.
Petroleum and mining	50 – 150	The overall fluoropolymer demand for petroleum and mining applications is expected to experience a slow growth in the short-term, but this trend may stabilise or even reverse in the mid- and long-term. The demand for different fluoropolymer products differs, and will depend on the increased regulatory specifications e.g., for reduced emission and the need for increased performance. The EU Green Deal and decarbonisation goals may also impact the petroleum market for fluoropolymers, as the extraction operations may fall in the coming decades. Dossier submitters expect petroleum and mining use to decline in the coming decades, with oil and gas infrastructure becoming decommissioned. Nevertheless, they have assumed a 1% growth rate for their assessment.

Sector of use	Fluoropolymers sold in EU in 2022 (in € million)	Future market trends forecasts
Food contact materials (FCM) and packaging (excl. lubricants)	50 – 150	In general, FPG members expect the overall FCM market for fluoropolymers to generally remain stable or contract in the short- and long-term. Individual applications can show different trends, but the overall expectation is declining. This depends on the regulations for food and feed processing. Industrial use of fluoropolymers (e.g., as seals or processing aids) is expected to increase slightly to comply with stricter standards. Consumer usage is expected to drop as a result of the proposed restriction. Dossier submitters, on the other hand, expect a stronger increase for consumer cookware (6%) and a more contained one for industrial uses (1.5%).
Electronics and semiconductors	100 – 250	The general consensus is that the electronics and particularly the semi-conductor sectors are going to drive a strong growth trend for fluoropolymers. Fluoropolymers are essential for manufacturing of semiconductors. The increased digitalisation in the EU with more devices entering the market and the increase in semiconductor production in the region are expected to increase demand for fluoropolymers in the short- and the long-term. A growth rate of 10% per year as assumed by the dossier submitters is not unrealistic.
Water and wastewater treatment	10 – 100	FPG members expect the demand for fluoropolymers by the water and wastewater treatment sector to increase in the short- and long-term, mainly as a result of the expected increase in need for potable and clean water and the high water quality standards in the EU.
Lubricants	100 – 250	Dossier submitters have not considered at all this very important market sector in the restriction proposal. FPG members expect slow to no growth for their fluoropolymers intended for the lubricants market segment. This could be attributed to the expected drop in internal combustion engine (ICE) vehicles and the increase of demand for electric vehicles (EVs) in the mid- to long-term in the EU. The dossier submitters are assuming a strong growth until 2030, with a slowdown in the years after that (2.5% until 2040 and 1% afterwards).
Medical devices	50 – 150	Overall, medical device applications of fluoropolymers are expected to grow strongly (up to 10% per year) in the short- and long-term. This can be due to new applications of fluoropolymers, but it is also due to the ageing population of Europe, which is expected to increase the need for operations using such products (e.g., stents). The information provided by FPG members agrees in principle with what the dossier submitters have included in Annex E to the restriction proposal, though the dossier submitters assume a slightly lower growth rate at 5%.
TULAC (Textiles, upholstery, leather, apparel and carpets)	50 – 150	FPG members expect overall sales to drop in the mid- and long-term, mainly driven from companies moving away from consumer uses. Professional use for safety clothing is expected to have a steady increase. Dossier submitters expect an overall strong growth in the short-term (5-8% pa) and a slower one in the long term (1-2% pa)
Metal plating and manufacturing of metal products	0 – 150	Limited information available on growth. In general, it can be assumed to remain stable in the baseline scenario, even if some applications in harsh conditions exhibit growth.

Sector of use	Fluoropolymers sold in EU in 2022 (in € million)	Future market trends forecasts
		Dossier submitters assumed no growth.
Cosmetics and personal care	5 – 10	Overall, sales are expected to remain stable, according to information received from FPG members.
Ski treatment (waxes)	0 – 20	Dossier submitters assumed no growth for the sector. Limited information available from FPG members, but general consensus is that its usage will go down.
Consumer mixtures	0 – 10	Dossier submitters assumed a significant decline of 8% per year until 2030 and 1% between 2030 and 2040. Limited information available on market trends. In general, it can be assumed that any remaining consumer applications of fluoropolymers will remain stable.
Other	10 – 100	Dossier submitters did not consider any market trends.
Total	1,020 – 3,000	It is expected that the overall demand for fluoropolymers will increase in the short- and long-term, as a result of the EU's policies for decarbonisation, cleaner environment and adoption of new technologies. Climate change is also expected to influence many decisions into adoption of more efficient solutions (such as protective architectural coatings), which rely on fluoropolymer technology.
Notes: Upper limit intentionally high to ensure that the individual companies' revenue could not be back calculated		

4.2 Description of possible no derogation scenarios

4.2.1 *Relevance of proposed and considered derogations to fluoropolymers*

The PFAS restriction proposal is intended as a broad restriction, with a small number of specified categories that are specifically excluded from the restriction proposal (see paragraph 4 in the second column of the restriction proposal) and include uses that are covered by other legislations, such as biocidal and plant protection and pharmaceutical and veterinary active substances. There are 46 proposed and considered targeted time-limited derogations are included in the proposal.

The time-limited derogations are for specific applications and conditions. Table 4.4 presents the proposed and considered derogations in the proposal that are relevant to fluoropolymers along with the estimated relevant fluoropolymer quantities. The latter have been estimated based on publicly available information (e.g., in the restriction proposal annexes) and using a number of assumptions. To mitigate the uncertainty, ranges were used where data were limited.

Table 4.4 Estimation of fluoropolymer quantities covered by the proposed derogations

Sector of use	Total quantities (in t)	Share of quantities covered by proposed derogations	Share of quantities covered by considered derogations	Quantities not covered by a derogation (t)	Comments / Discussion
Transportation and aerospace	11,000 – 20,000	0%	10-25%	9,900 – 15,000	The definition of the considered derogation on transport applications 6(o) is unclear and may be open to conflicting interpretation by manufacturers and authorities. On one hand, companies could claim that all fluoropolymer components and coatings are essential for the safety of a vehicle, its passengers or the cargo. On the other hand, there may be cases where this is not perfectly clear. It seems safe to assume that all fluoropolymer uses in aviation (e.g., fuselage manufacturing, cable insulation, and cable conduit) are covered. Automotive / land transport uses are more uncertain. Therefore, a medium weight coverage should be assumed. It should also be noted that the considered derogation does not cover use of electrical or electronic systems or lubricants. No derogations proposed for this use sector, and the use is not described at all in the restriction proposal documents. No derogations proposed for this use sector
Industrial applications (chemical industry)	8,000 – 16,000	0%	0%	8,000 – 16,000	The only proposed derogation for the whole energy sector is for PEM fuel cells. While this is an important use, it does not include other important fluoropolymer uses such as binders in Li-ion batteries, ionomers for hydrogen electrolyzers, coatings in PV panels and wind turbine blades, as well as sealing in power plants, and cable jacketing. As such, the covered quantities by this derogation are expected to be very low.
Construction materials and products	5,000 – 10,000	0%	0%	5,000 – 10,000	
Energy applications, including batteries and hydrogen	5,000 – 10,000	0-10%	0%	4,500 – 9,000	It appears that fluoropolymer applications in petroleum and mining are covered by this derogation. This does not appear to cover downstream refining and processing of the extracted resources, however, a high coverage rate is assumed for this derogation.
Petroleum and mining	2,500 – 10,000	50 – 100%	0%	0 – 5,000	

Sector of use	Total quantities (in t)	Share of quantities covered by proposed derogations	Share of quantities covered by considered derogations	Quantities not covered by a derogation (t)	Comments / Discussion
Food contact materials and packaging (excl. lubricants)	2,500 – 6,000	12.2 – 16.6%	3.1 – 4.2%	2,120 – 4,750	There is one proposed and one considered derogation, both of which relate to industrial / commercial applications of fluoropolymers in the food processing sector. According to the information in Annex A to the restriction proposal (section A.3.3), industrial applications account for 15.3-20.8% of the total quantities of fluoropolymers used in this sector of use. It is unclear, however, how much of it is used in industrial processes (proposed derogation) and how much for industrial and professional bakeware. Considering the extensive use of fluoropolymers in the food and feed processing industry, an 80/20 split will be assumed for this exercise.
Electronics and semiconductors	2,000 – 6,000	0%	11.3 – 22.5%	1,780 – 4,850	Annex A to the restriction proposal (Section A.3.12.2), estimates that 45% of fluoropolymers are used in semiconductors and 55% in other electronics. According to the submission of the European Semiconductor Industry Association to the OPC (response No 4449), “...the semiconductor industry is very reliant on PFAS materials. Those materials are used in manufacturing process chemistries, in specific semiconductor functional layers and packages, semiconductor manufacturing equipment, semiconductor manufacturing infrastructure, and support equipment in addition to the semiconductor device”. The considered derogation on semiconductors refers to the manufacturing process, and it is not clear if it also covers the equipment, site infrastructure and final products (semiconductor chips), which may contain fluoropolymers. As it stands, it could result in most of the fluoropolymers used in “packaging” of semiconductors, as well as components of manufacturing equipment (such as sealings and linings) not being within scope. Therefore, a mid-range coverage (25-50%) is assumed for this derogation.

Sector of use	Total quantities (in t)	Share of quantities covered by proposed derogations	Share of quantities covered by considered derogations	Quantities not covered by a derogation (t)	Comments / Discussion
					There is no derogation for electronics, though some may be covered in derogations for other applications (e.g., in transportation), the majority seems to be out of scope.
Water and wastewater treatment	1,000 – 6,000	0%	0%	1,000 – 6,000	No derogations proposed for this use sector, and the use is not described at all in the restriction proposal documents.
Lubricants	500 – 2,500	25-50%	0%	375 – 1,250	The wording in the proposed derogation is unclear and may lead to conflicting interpretations by the industry and the authorities. 'Harsh conditions' are not specified quantitatively, and the "safe functioning and safety" of equipment could be interpreted too broadly or too narrowly. As such, a conservative impact of 25-50% of fluoropolymer lubricants are considered covered.
Medical devices	300 – 2,000	25-50%		225 – 1,000	The use of fluoropolymers in medical devices is very extensive, mainly as coatings, but they are also used as component materials. The restriction proposal includes a number of proposed and considered derogations for use of PFAS and fluoropolymers in medical devices. The specific quantities of fluoropolymers used in these particular applications are not clear. There is a considered derogation 6(j) on "coating applications for medical devices other than Metered Dose Inhalers", which is the main application of fluoropolymers. Also considering that some uses of fluoropolymers (e.g., in laboratory equipment) do not seem to be covered by a derogation, it is assumed that 25-50% of fluoropolymer use in medical devices will be covered by the proposed and considered derogations.
TULAC (Textiles, upholstery, leather, apparel and carpets)	800 – 2,000	5.4 – 13.6%	0.8 – 5.1%	750 – 1,630	There are proposed derogations for some PPE categories and for technical textiles. According to the information in Annex A to the restriction proposal (section A.3.3), professional apparel accounts for 15.5-17.3% and technical textiles for 15.4-20.3% of fluoropolymers used in textiles. PPE are an unspecified share of professional apparel and approximately 20% of PPE are for Category III hazards. It can be assumed then that the professional apparel derogations 5(b) and (c) cover 10-20% of the fluoropolymer use in that group.

Sector of use	Total quantities (in t)	Share of quantities covered by proposed derogations	Share of quantities covered by considered derogations	Quantities not covered by a derogation (t)	Comments / Discussion
					The technical textiles use in filtration and separation media where both oil and water repellence are required are a smaller subset and do not cover the whole technical textile usage. The actual share is unclear, so a conservative 25-50% share is assumed. The considered derogation for use in engine bays in cars is a relatively small share of technical textiles, so it is assumed to account for 5-25% of the respective usage.
Metal plating and manufacturing of metal products	20 – 200	0%	5-25%	15 – 150	The considered derogation is for the use of PFAS in hard chrome plating, where fluoropolymers have very few, if any applications. Most fluoropolymers in this use sector appear to be used in manufacturing of metal products, which do not have a derogation. It is possibly that fluoropolymers may be used in plant equipment as seals or other components, but this could not be confirmed. Nevertheless, following a more conservative approach, a 5-25% relevance will be assumed.
Cosmetics and personal care	100 – 1000	0%	0%	100 – 1,000	No derogations proposed for this use sector
Ski treatment (waxes)	0 – 20	0%	0%	0 – 20	No derogations proposed for this use sector
Consumer mixtures	1 – 100	0%	0%	1 – 100	No derogations proposed for this use sector
Other	1,000 – 2,000	0%	0%	1,000 – 2,000	No derogations proposed for other use sectors
Total	40,000 – 95,000			34,766 – 77,750	

In total, the proposed derogations would only cover **13 - 17%** of the fluoropolymer sales volumes in the EEA by FPG members.

Some use sectors of particular interest are:

- The **chemical processing industry**, which accounts for a large share of the manufactured and sold fluoropolymers in the EU, has not been considered at all in the restriction proposal and there are no explicit derogations or exemptions. As such, the whole usage of fluoropolymers in this sector, which includes seals, pipe and vessel linings, potable, waste- and industrial water treatment membranes and also filters and ion-exchange membranes, are currently not covered by a derogation.
- In addition, there is a need for PTFE micropowders for manufacturing using high-performance resins, such as PEEK, PAI and PI. Furthermore, composite materials and other high temperature polymers that require mould release agents are not covered by the proposed derogations. However, they constitute a significant share of fluoropolymer usage and can have a significant impact in the output and quality of high-performance polymer manufacturing.
- **Energy applications** only have a proposed derogation for PEM fuel cells, which is only a small part of the extensive applications of fluoropolymers in the sector. This leaves most of the fluoropolymer usage for energy applications not covered by a derogation and, ultimately, lost if the scope of the currently proposed derogation is not changed. Such uses include binders in batteries, electrolysis membranes for hydrogen production, seals and wiring for conventional and nuclear power plants. Seals and wiring are critical to the safety of nuclear power plants, which generated 21.9% of the EU's electricity in 2022¹⁴.
- The **transport and lubricant** derogations lack sufficient clarity, which risks conflicting interpretations by different actors, and could result in many applications not being covered by a derogation.
- **Construction** applications are also not covered by derogations, despite the difficulty to identify and implement alternatives for critical uses, such as electrical installations, bearings for bridge and wind turbine bases, and protective (conformal) coatings.
- The partial derogation for **semiconductor manufacturing**, which seems to exclude the range of uses and materials needed for manufacturing as well as in any semiconductor products placed on the market as well as those that can be found in the whole range of electronic and other consumer products. This leaves a large share of fluoropolymers used by the industry not covered by a derogation.

Overall, some of the most critical and extensive uses of fluoropolymers, for which substitution is very difficult, if not impossible, within the restriction proposal's derogation 6.5- or 13.5-year timeframes, are not covered by the proposed or considered derogations and will need to stop within 18 months of the restriction's entry into force unless taken into scope in the next phase of the PFAS restriction proposal process.

4.2.2 *Scope of impacts for the fluoropolymer industry*

The proposed restriction as it stands would seriously limit the operations of fluoropolymer manufacturers, as it will prohibit the manufacturing and placing in the market most of their output. As estimated in Section 4.2.1, more than 80% of the fluoropolymer manufacturers sales would be impacted by the currently proposed restriction.

This must be considered with the lack of alternatives for the majority of the uses, even those that do not have a proposed derogation, as discussed in Chapter 3 of the previously submitted response by FPG. In addition, the long times needed to identify, develop and qualify alternatives for most applications do not allow for sufficient development of these alternatives. The absence of alternatives can even affect the uses of fluoropolymers under the derogations that have been proposed. It is very likely that suitable alternatives may not be available even after the proposed derogation periods expire. As a result, the current restriction proposal carries a

¹⁴ European Council website – Infographic: How is EU electricity produced and sold? Available online at: <https://www.consilium.europa.eu/en/infographics/how-is-eu-electricity-produced-and-sold/#:~:text=In%202022%2C%2039.4%25%20of%20electricity,Coal%3A%2015.8%25>, accessed on 07 September 2023

significant risk that function of critical operations and manufacture of important products in the EU will not be possible without broader, or more specific and detailed, and longer derogations.

Such a large restriction will make most fluoropolymer manufacturing lines unsustainable, which will lead to their shutting down in the EEA. In general, fluoropolymer manufacturing lines are specialised for this particular production process and cannot be repurposed for other non-fluorinated products. As fluoropolymers are specialty chemicals, they are typically manufactured in smaller quantities, and, therefore, the tanks and reaction vessels are generally smaller than those needed by other, more bulk, chemical processes, so it will be difficult, and may not make sense financially, to repurpose them for other products. In general, each polymerisation chemistry requires different sets of operating conditions and, consequently, a different design with regards to construction materials and the equipment overall. In addition, certain fluoropolymers, such as PTFE, are produced using highly specific manufacturing technology that are not common to other products, so it is unlikely that all the equipment can be adapted to a new use.

Furthermore, as some manufacturers specialise in fluorinated chemistry, switching their production lines to completely different chemistries is not a short- or even long-term possibility. Pivoting into completely new processes and markets is a process that typically takes many years, even decades, and it is not possible in the short timeframes available until the PFAS restriction's entry into force. The importance of the difference between types of polymerisation chemistries and their specific manufacturing processes (operating conditions, materials requirements) is fundamental to understanding that a manufacturing facility for a fluoropolymer cannot be used to manufacture another polymer.

Whether shutting down of fluoropolymer production lines will lead to wider plant closures depends on the extent to which the plants rely on fluoropolymer products. In general, fluoropolymer manufacturers expect the following impacts to their plants, depending on their individual circumstances:

- Shutting down only of specific product lines, which are used in fluoropolymer manufacturing, but no additional impacts for the rest of the plant.
- Shutting down of whole plants, as they usually rely extensively, or exclusively, on the manufacturing of fluoropolymers.

These plants are often multi-product facilities that need to have sufficient production output to support the overall operations. This is particularly important if those operations include upstream manufacturing of monomers and other raw materials used in fluoropolymer manufacturing. Such operations need to have sufficient scale of demand to continue to operate efficiently. If the demand drops significantly, as is expected in case the PFAS restriction applies as per the current proposal, upstream production lines in the EEA would also become uneconomical in most cases, leading to line and potentially plant closures.

The line and plant closures in the EEA would significantly reduce the availability of fluoropolymers in the EEA and globally, as the EEA and the UK are among the largest manufacturers globally. The EEA is also a major exporter of fluoropolymers, with approximately 24,000 tonnes exported outside EU28/EEA in 2020 and 15,000 tons imported. Shutting down of the EEA plants would mean that manufacturers will need to increase their non-EEA capacity to cover the non-EEA and derogated demand that is currently covered by the EEA plants. This cannot be completed in the short term, as expanding or building lines requires careful planning, construction time and optimisation. The global fluoropolymer industry as a whole has been working with little spare capacity, so it will be very difficult for non-EEA plants to take over additional manufacturing orders. Nevertheless, the situation for the specific fluoropolymers when examined separately may differ, with those that are primarily manufactured in the EEA (such as FKM) facing a highest risk of shortages than those whose manufacturing is spread more broadly (e.g., PTFE). It should be noted that, construction of a new fluoropolymer manufacturing line can cost tens to hundreds of million euros, depending on the size and will need several years of planning, construction, and start up.

In any case, the restriction proposal would prevent both the manufacturing and the import of fluoropolymers in the EEA, as raw materials, components or part / coating of equipment. That means that, even if manufacturing was possible in non-EEA locations in the short-term, import would still not be allowed, and the overall impacts for the EEA economy and society would in the end be the same.

A shutdown of practically all fluoropolymer manufacturing in the EEA could, therefore, impact the availability of fluoropolymers even for derogated uses in the EEA, and potentially globally.

Such a shutdown would also have serious impacts on the EU's strategic autonomy (EU-SA) objectives. The EU-SA refers to the capacity of the EU to act without excessive reliance on third countries in strategically important policy areas, such as energy supply, defence and the economy in general¹⁵. Many of the industry sectors relying on fluoropolymers, such as transportation and aerospace, medical devices, energy, semiconductors and electronics, etc., are considered critical for the EU and need secure supply of their raw materials and components. At the moment, EEA supply of fluoropolymers relies mostly on local manufacture. A significant increase in imports of fluoropolymers, if allowed, would jeopardise the goal of reducing foreign dependence for critical materials and components under the EU-SA concept.

In summary, the implications of implementing the PFAS restriction as it stands, without additional derogations or an exemption for use of fluoropolymers are as below:

- Shutting down of all fluoropolymer production in the EEA. This also includes upstream manufacturing and supporting operations (e.g., R&D, sales).
- Relocation of remaining production to non-EEA facilities, as the remaining output of EEA plants will not be economically sustainable.
- Relocation would require increasing capacity of existing facilities or building new ones, which would require several years to complete.
- Availability of fluoropolymers in the EEA will be very limited and may not even be sufficient for derogated uses, as non-EEA plants will not be able to cover the demand.

4.2.3 Scope of impacts for downstream users of fluoropolymers

How downstream users will react in case it is not possible to sell fluoropolymers in the EEA depends on the following factors:

- Whether a feasible non-fluoropolymer alternative is available at sufficient quantities. If companies can use an alternative for their application, they will do it. However, companies may not wish to use a material or product that has worse performance or worse durability than fluoropolymers, as this could increase the risks for human health and the environment or it could result in lower quality or unreliable products. For example, automotive or aircraft manufacturers would not accept using a part that would not perform according to their very stringent reliability and safety specifications. Similarly, food processing processes need to maintain a very high standard of cleanliness and hygiene, which may not be possible with alternative materials. As discussed in Chapter 3 of the previously submitted response by FPG, suitable alternatives may be available for a limited number of applications that do not need to meet very demanding specifications.
- Whether the fluoropolymer is used in the process or is part of the final product. In the former case, e.g., in chemical processing, the final product does not contain PFAS and thus it is possible for the entire manufacturing process to move to a non-EEA location, provided there is sufficient production capacity. In the latter case, the product containing fluoropolymers will not be available in the EEA and the user may not be able to offer it or their services to EEA customers. Such examples are sealing equipment, binders for batteries, membranes used in electrolysis and filtration equipment, etc. Note that the current restriction proposal would also impact the potential import of such products. This could have significant impacts on industrial operations in the EEA, with many high-end technology products not being able to be produced.

It should also be noted that almost all proposed derogations are time limited. Manufacturers of fluoropolymers would thus eventually have to stop any production and use of fluoropolymers in all applications in the EU would cease. Considering the lack of alternatives and the difficulty in identifying suitable

¹⁵ European Parliament website - EU strategic autonomy 2013-2023: From concept to capacity. Available online at: [https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI\(2022\)733589](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2022)733589), accessed on 25 August 2023

alternatives and substituting fluoropolymers within the stipulated timeframe, most of the downstream users of fluoropolymers and fluoropolymer articles and coatings would need to cease their operations, leading to potential discontinuation of product lines.

Inability to use fluoropolymers across the range of the applications described in Section 3.3 of the previous report and summarised in Table 3.1 will have severe impacts in all those industry sectors and the EEA society and economy in general, as will be discussed in the following sections.

4.3 Impacts of a no derogation scenario

4.3.1 Indicative economic impacts

4.3.1.1 Manufacturers and importers in the EU

In 2022, the value of fluoropolymers produced and imported in the EU by FPG members participating in this study was in the range of € 1.0 – 3.0 billion, as shown in Table 4.3. The overall trend for fluoropolymer demand in the short-term is expected to be a slow growth in most markets in a baseline scenario. However, the expected pressure from customers to move to non-PFAS alternatives could restrain that growth if alternatives are developed and tested successfully. Nevertheless, it is expected that this organic substitution of fluoropolymers in some less demanding applications will not have a significant impact on overall demand and the value of fluoropolymers from FPG members would remain in that range.

If the PFAS restriction is adopted as currently proposed, the small share of fluoropolymers that will be covered by the proposed time-limited derogations will not be sufficient to support the manufacturing activities in the EU and it is possible that the FPG members' plants will be forced to shut down their fluoropolymer operations. Therefore, the whole value of € 1.0 – 3.0 billion per year will be lost.

It is unlikely that this will be replaced by value generated by alternative materials or processes, considering the overall difficulty in identifying suitable alternatives to fluoropolymers, as presented for the different market sectors in Section 3.3 of the previous FPG response. This could change slowly over time but cannot be predicted.

The value of €1.0 – 3.0 billion per year refers to the estimated 2022 revenue of the FPG members that participated in the study. Projecting to 2025, using the expected growth rates for each use, as presented in Table 4.3, would give a value of the fluoropolymers manufactured and sold in the EEA in the range of €1.2 – 3.5 billion. Maintaining the same annual growth rate until 2030 would give a Net Present Value of €6.2 - 18 billion for the 2025 – 2030 period, discounted to 2025 prices.

4.3.1.2 Downstream user sectors

The value of the fluoropolymer industry by itself can be considered relatively modest when compared to the total output of the EU economy. However, as discussed in Section 3.3 of the previous report, fluoropolymers are used in a broad range of applications, supporting a diverse group of critical applications, such as vehicle safety, semiconductor manufacturing, drinking water and wastewater treatment and various energy-related applications. The value of these markets is many times higher than that of the fluoropolymers. Table 4.5 summarises the combined value of those EU markets that rely extensively on fluoropolymers, based predominantly on publicly available information.

It should be noted that the information in the following table is for illustrative purposes and is intended to give an indication of the magnitude of the importance of fluoropolymers in the whole EU economy. The numbers are mainly based on assumptions, described in the "Discussion" column of Table 4.5, as more specific information was not available to FPG members. Depending on the available information, different approaches were followed for each market sector. It is understood that the relevant industry associations (e.g., Euratex for textiles, CEFIC for chemical processing, ACEA for automotive, ESIA for semiconductors) will submit more specific information to the open public consultation on use and application information, as well as the impacts in their sectors.

Table 4.5 Size of markets relying on fluoropolymers

Sector of use	Current market value in € (where available)	Source	Assumed value of market relying on fluoropolymers	Discussion
Transportation and aerospace (excluding lubricants)	Automotive: 390 billion manufactured in 2021 1.12 trillion in sales in 2019 according to Eurostat Aviation: 241 billion direct turnover (578 billion including indirect and induced)	[1] [2] [3] [4]	Automotive: €195-390 billion Aviation: €60 – 120 billion	12.1 million cars were manufactured in the EU in 2021 (and a total of 13.1 million vehicles, including vans, trucks and buses). The average car price in Europe in 2020 was approximately €32,000, approximately 15% higher than in 2015. This gives an average value of automotive output at approximately € 390 billion. Fluoropolymers are essential components that ensure safety and effective operation of the vehicles and they are highly durable even at extreme operating conditions. It can thus be assumed that up to 100% of the value of the automotive sector produced in the EU, including a €101.9 billion trade surplus, is relevant to fluoropolymer use. The aviation industry revenue includes production of civil aircraft, aircraft engines, parts and components. The total market value accounts for revenue for civil aeronautics and civil space applications, according to the ASD economic impact brochure. Not all of the manufactured parts and components rely on or use fluoropolymers, but there are several critical applications which could impact the safety or performance of parts or even the whole aircraft. Without more detailed information on the breakdown of the aviation market, only assumptions can be made. For the purposes of this exercise, a factor of 25-50% is assumed.
Industrial applications (chemical industry)	€ 593.7 billion in 2021 of which: € 153.4 billion petrochemicals € 26.9 billion inorganic € 16.1 billion industrial gases € 29.3 billion fertiliser and N-compounds € 109.2 billion primary plastics €4.6 billion synthetic rubber € 7.8 billion man-made fibres	[5]	€ 65.8 – 193.5 billion in 2021	Fluoropolymers are used in sealing equipment, pipe and vessel linings, coatings, as well as filters and other equipment in chemical manufacturing processes, especially where extreme / harsh conditions are expected (very high or cryogenic temperatures, high pressures or vacuum, corrosive or very reactive chemicals, mechanical stress, etc.). In addition, seals are also important in containing hazardous substances and preventing leaks and unwanted release in the workplace and to the environment. The actual share of chemical processes using fluoropolymers cannot be known with precision. It is understood that petrochemicals and the inorganic chemicals industries (particularly the chloralkali industry) rely heavily on fluoropolymers, with the other sub-groups using fluoropolymers to a smaller, but critical, degree. It should be noted that many of the chemical products from these processes are used in other processes downstream or in different industry sectors (e.g.,

Sector of use	Current market value in € (where available)	Source	Assumed value of market relying on fluoropolymers	Discussion
	€ 10.5 billion dyes and pigments € 13.5 billion agro-chemicals € 45.5 billion paints, varnishes & coatings € 96.5 billion other chemicals € 80.3 billion consumer chemicals			in manufacturing as processing aids or components). As such, they support a larger market share than that calculated here.
Construction materials and products	€ 13 trillion GDP	[6]	Expected to be in the range of tens of billions	Fluoropolymers are used in various construction applications, offering protection against the elements and excellent overall durability over the building's lifetime. However, their value is mainly measured against the reduced need for maintenance and limited loss of performance over time when compared with alternative materials. As such, it is not possible to calculate the exact share of the overall construction industry relying on fluoropolymers, but there is wide use for certain applications, such as coatings for roofs and facades, bridge and wind turbine base bearings, greenhouse films, and PTFE thread sealings for piping. Fluoropolymers are essential for Li-ion batteries, as alternative binders are not suitable and it could take several years to identify and implement a substitute. The EU market can increase from €340 million in 2016 to €3-14 billion in 2025 and fourfold that by 2030, stimulated primarily by the increased demand for electric vehicles and for energy storage. All hydrogen-related projects, both for electrolyser applications and for fuel cells (for vehicles or other end uses), rely on the use of fluorinated ionomers and PTFE. As alternatives are not suitable (Section 3.3.4 of the previous report), it can be concluded that up to 100% of the value of hydrogen applications relies on use of fluoropolymers.
Energy applications, including batteries and hydrogen	Batteries: 3-14 billion in 2025 (projected) Hydrogen: 21 billion for fuel cells by 2030 18.75 billion in electrolysers by 2030	[7] [8]	Batteries: 1.5-14 billion in 2025 (projected) Hydrogen: up to € 39.8 billion by 2030	Fluoropolymers are essential in a broad range of applications in the oil and gas extraction sector, as well as downstream, in transport and refining of petroleum products. Considering the lack of suitable alternatives and the difficulty in substitution it can be assumed that up to 100% of the value of oil and gas extraction in the EEA may rely on the use of fluoropolymers.
Petroleum and mining	29.95 billion in 2019 for O&G extraction in EU 55.2 billion in 2019 in Norway	[9]	€ 42.6 – 85.2 billion in 2019	As discussed in Section 3.3.5 of the previous report, fluoropolymers are essential in a broad range of applications in the oil and gas extraction sector, as well as downstream, in transport and refining of petroleum products. Considering the lack of suitable alternatives and the difficulty in substitution it can be assumed that up to 100% of the value of oil and gas extraction in the EEA may rely on the use of fluoropolymers.

Sector of use	Current market value in € (where available)	Source	Assumed value of market relying on fluoropolymers	Discussion
Food contact materials and packaging (excl. lubricants)	Industrial: 1.1 trillion (added value of 222 billion)	[10]	Consumer: € 2 billion Industrial: € 550 billion	The whole food and feed processing industry could be relying on the use of fluoropolymers. As discussed in Section 3.3.6 of the previous report, there are no suitable alternatives for such applications, as the most likely alternatives are less durable and would need replacement more often. Nevertheless, it is understood that, in some lower-end applications, fluoropolymers may be possible to substitute with lower performing materials. Therefore, as a conservative assumption, it will be assumed that 50% of the food and feed industry output will be relevant to fluoropolymer use. Annex E to the restriction proposal also refers to a value of €2 billion for consumer products, based on PlasticsEurope data from 2018. It can be assumed that this value has remained stable until now.
Electronics and semiconductors	Semiconductors: 53.8 billion in EU Electronics: 88.7 billion in 2022 (projected)	[11] [12]	€ 26.9-53.8 billion in 2021 – to increase significantly by 2030 € 8.7-26.2 billion in 2022 (projected)	EU semiconductor manufacturing relies completely on PFAS in general and fluoropolymers specifically. Filters and sealing for manufacturing equipment are essential for the high-cleanliness semiconductor fabrication environments. Therefore, it is assumed that up to 100% of the value of the semiconductor industry is relevant to fluoropolymer use. The knock-on benefits from the use of semiconductors downstream can be orders of magnitude higher, considering they are used in practically all information and telecommunications equipment, as well as consumer and industrial electronics. Semiconductors are also expected to be increasingly used in automotive electronics, with more electronics and automated control in newer vehicle models. Fluoropolymer use in electronic equipment also includes coatings, sealing and cable / wire jacketing, particularly for equipment that is expected to operate in harsh environments, with extreme temperatures, aggressive chemicals and constant mechanical stress. Industrial electronics manufactured in the EU, with applications in manufacturing, testing and measuring, transportation, power applications, as well as home and building automation, had a value of 74.3 billion in 2016, with a CAGR of 4% since 2010. Using a smaller, 3% annual growth rate, to account for the Covid-19 pandemic, the market could be worth close to € 89 billion in 2022. Fluoropolymers may be used in all these applications, but they appear to be extremely important for factory applications and testing (as many DU have mentioned the importance of using FP-jacketed cable in sensors and

Sector of use	Current market value in € (where available)	Source	Assumed value of market relying on fluoropolymers	Discussion
Water and wastewater treatment	€640 million for ultrafiltration membrane market	[13]	€470 million for ultrafiltration membranes Much higher value for projects using ultrafiltration membranes	metering devices), as well as transportation and power. For the purposes of this exercise, a 25-50% factor will be assumed for the factory applications and a smaller, 5-25% for the rest. The most obvious application of fluoropolymers in water and wastewater treatment is in filtering membranes, used to remove contaminants from the water. There are also other applications, such as piping, sensors and pipe sealing. According to market research, the value of the ultrafiltration membranes global market was approximately \$4.2 billion in 2021 and was expected to grow at a CAGR of 5.9% to \$5.8 billion by 2026. Approximately 18% of the global volume was sold in Europe, which gives an estimate of approximately \$750 million (€640 million). The same report estimates that approximately 95% of the membranes sold, by volume, were polymeric, and the remaining were ceramic. Approximately 77% of the polymeric membranes were fluoropolymers, i.e., PVDF. This would give a market value for ultrafiltration membranes of approximately €470 million in 2021, but the actual value of the projects supported by these components is much higher.
Lubricants			Covered by other sectors of use	Fluoropolymer lubricants have a broad range of applications, as discussed in Section 3.3.9 of the previous report. Indicative sectors of application of PFPE- and PTFE-based lubricants include automotive, aerospace, industrial machinery, construction, etc. As such, all connected market value is covered by the discussion in the respective sectors and mentioning it again in lubricants could lead to double counting.
Medical devices	€150 billion, of which € 14 billion for IVD	[14]	Expected to be in the range of tens of billions. More specific information may be available at MedTech Europe's response to the open public consultation. (Volume 33; comment #6208)	Fluoropolymers are mainly used as coatings in medical devices, but the share of impacted medical devices is unclear, especially considering the very large number of different medical devices and IVDs (more than 500,000 different products). They are used in a broad range of different devices, such as invasive devices (stents, catheters, sutures, hernia meshes), in components for treatment of serious diseases, in ophthalmic products, as well as in IVD instruments ¹⁶ .

¹⁶ MedTech Europe PFAS briefing 27 February 2023. Available online at: https://www.efim.eu/upload/docs/230227_MTE_PFAS_Briefing_DRAFT_V3.pdf, accessed on 24 August 2023

Sector of use	Current market value in € (where available)	Source	Assumed value of market relying on fluoropolymers	Discussion
Cosmetics and personal care	88 billion (retail value) > 29 billion added value	[15] [16]	€ 410 million (retail value) € 130 million (value added)	According to Annex A to the restriction proposal, the share of cosmetic products containing PFAS was approx. 1.4% in 2019. This refers to number of products, so the actual volumes and sales will likely be different, but not significantly so. It is understood that not all of these products contain fluoropolymers, though PTFE is among the most frequently ingredients mentioned. Without more detailed information available, it can be assumed that fluoropolymers account for one third of these uses.
TULAC (Textiles, upholstery, leather, apparel and carpets)	147 billion produced in EU-27	[17]	€ 20.4 billion in 2021	According to EURATEX, industrial and technical textiles account for 17% and man-made fibres for 5% of total EU production. Home textiles account for 14% and fabrics for 15%. Not all of this production uses fluoropolymers, but, considering the importance of fluoropolymers for technical and industrial textiles, it can be assumed that more than 50% of these rely on fluoropolymers. For the other categories, a more modest share of 5-25% is assumed.
Metal plating and manufacturing of metal products	Not available		Not available	The dossier submitters estimated a usage of 900 tpa of fluoropolymers in manufacturing of metal products. FPG members have declared sales volumes of 20-200 tpa, but this value may be larger, as distributors may be selling to various markets, which behaviour is not captured by the FPG members' sales departments.
Ski treatment (waxes)	51 million	[18]	0	Fluoropolymers are used in a small share of ski treatment waxes, but the majority of PFAS used therein are perfluoroalkanes or semi-fluorinated alkanes. As such, and considering that neither FPG members nor downstream users of fluoropolymers mentioned this application in their operations, the share will be assumed to be zero.
Consumer mixtures	10-30 million for guitar strings Unclear for other applications	[18]	€ 10 – 30 million	The tonnage of fluoropolymers intended for consumer mixtures is very low and it is expected to be phased out in the near future. Currently, fluoropolymers are used mainly in waxes and polishes. The overall value of the remaining relevant markets cannot be estimated from the available information. Therefore, only the conservative estimation of the guitar string market segment is considered.
Total			More than € 900 – 1,400 billion (rounded)	The sum value to the left does not include the potential impact for hydrogen technologies, which even though they have a relatively small value currently,

Sector of use	Current market value in € (where available)	Source	Assumed value of market relying on fluoropolymers	Discussion
				are expected to expand significantly in the near future and reach approximately € 40 billion by 2030 and even more in the long-term. It should also be noted again that this value holds significant uncertainty and is used to illustrate the value in the downstream market sectors that potentially rely on fluoropolymers. Compared to the value of the fluoropolymers themselves it is two to three orders of magnitude larger. <u>Nevertheless, it must also be noted that this should not be interpreted as potential economic impacts in case fluoropolymers are not exempt from the PFAS restriction. It can be used, however, as an indication of the size of the EU economy connected to the use of fluoropolymers.</u>
Note: Where more precise information was not available, three main ranges were used to estimate the connection of a certain sector's output to fluoropolymers: • 50-100% for highly reliable data on applications • 25-50% for somewhat reliable data on applications • 5-25% for low level of reliability of data on applications The justification for the level of reliance is presented in the relevant cell in the "Discussion" column List of sources: [1]: https://www.statista.com/statistics/425095/eu-car-sales-average-prices-in-by-country/ [2]: https://asd-europe.paddlecms.net/sites/default/files/2022-11/EIS-brochure%20for%20web_pages.pdf [3]: https://ec.europa.eu/eurostat/databrowser/view/SBS_NA_IND_R2_custom_6924836/default/table?lang=en [4]: https://www.acea.auto/facts-about-the-automobile-industry/ [5]: https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/ [6]: https://ec.europa.eu/docsroom/documents/15866/attachments/1/translations [7]: https://euratex.eu/wp-content/uploads/EURATEX_FactsKey_Figures_2022rev-1.pdf [8]: https://op.europa.eu/en/publication-detail/-/publication/530105f4-493d-11ea-b81b-01aa75ed71a1/language-en [9]: https://ec.europa.eu/eurostat/databrowser/view/SBS_NA_IND_R2_custom_6924836/default/table?lang=en [10]: Amec Foster Wheeler, 2017 (Annex E) [11]: Submission 4449 to the OPC [12]: https://visitors-centre.jrc.ec.europa.eu/en/media/infographics/lithium-ion-batteries-scenarios-cost-and-market-growth [13]: https://www.bccresearch.com/market-research/membrane-and-separation-technology/ultrafiltration-membranes-techs-markets-report.html [14]: https://www.mediateurope.org/about-the-industry/facts-figures/ [15]: https://cosmeticseurope.eu/cosmetics-industry/ [16]: Annex A to restriction proposal (Section A.3.7) [17]: https://hydrogeneurope.eu/wp-content/uploads/2023/02/Hydrogen-Europe-position-paper-on-PFAS-ban_v12_FINAL.pdf [18]: Annex E to restriction proposal – consultation comments (Section E.2.5.4) [18]: Annex E to restriction proposal (Section E.2.7.4 – Table E.82)				

Table 4.5 highlights the importance of fluoropolymers across a broad range of industry sectors in the EU. This study estimates that fluoropolymers contributed to downstream products and operations worth between approximately €700 and €1,400 billion in 2022. Considering the expected growth in many of these sectors in the coming years as a result of market shift and the EU's policies, this number could be much higher by 2030 and even higher by 2040 and 2050. Also, as mentioned above, this is just an indicative value based on a number of assumptions.

If the same approach as the one for the fluoropolymer market (Section 4.3.1.1) is followed, the value of these markets in 2025 can be calculated at €1.0 – 1.5 trillion, and an overall NPV for the 2026 – 2030 period would be €4.8 – 7.2 trillion. Nevertheless, it must again be noted that these are illustrative calculations to highlight the importance of fluoropolymers to downstream markets and was based on very high level, and in places incomplete, data. Therefore, it should be considered and quoted with caution.

To these values, one should also add the importance of fluoropolymers in enabling tens if not hundreds of billions' worth of investments in innovative technologies and projects that contribute to the EU's climate change and decarbonisation goals for 2030 and 2050. Such technologies and projects include (green) hydrogen generation, storage and transport projects, batteries for energy storage and electric vehicles, as well as expansion of semiconductor fabrication capacity.

4.3.2 Societal benefits from applications of fluoropolymers

As shown in Section 3.3 of the previous report and summarised in Table 3.1, the range of fluoropolymer applications is very broad and spans the whole EU industry landscape. In most of these applications, substitution potential is low, due to the very high technical specifications and critical requirements of the use, which can only be met by fluoropolymers, and, in the event of a potential alternative being identified, the long substitution timelines often required by each industry sector's validation and qualification procedures. The lack of alternatives that can meet the performance and durability requirements in those applications underlines the importance of fluoropolymers for the continued offering of the relevant products and services that are critical for the EEA's industry, economy and society.

In general, fluoropolymers are usually selected as an option after non-fluorinated alternatives have been assessed and rejected for various reasons. As can be seen from the discussion on fluoropolymer applications, fluoropolymers are used where a combination of resistances to various harsh conditions over long periods of time is required for the product or process to meet critical performance specifications. Considering the fluoropolymers' comparatively higher unit costs, if more economically favourable alternatives were available, this would have been a driver for their substitution. As the potential alternatives have lower performance, increased weight and / or worse durability than fluoropolymers, using them may not be an option, especially in critical safety applications such as semiconductors and electronics, transportation, chemical and petroleum industries and food processing, as well as medical devices.

Table 4.6 provides an overview of the benefits to the EU from the use of fluoropolymers in the different use sectors.

Table 4.6 Summary of societal benefits from fluoropolymer applications

Use sector	Indicative uses	Benefits from the continued use of fluoropolymers
Transport, including automotive and aerospace	Fuel tubing and hose, engine oil and drivetrain seals (O-rings, gaskets), O-rings, seals, gaskets, ice-phobic coatings on helicopter rotor blades, window shades Exhaust gas pipes. Fuel cell membranes Oxygen, NO_x sensors, emission control systems. Pedal, battery, oil, radar, rain-light sensors Transmissions seals, thermal management systems Transfer or compression moulded automotive fuel Wires and cables Signal, control and power wires and cables insulated with fluoropolymers in military and civil aviation. Foams in aircraft insulation Electroluminescent lamps	Most land vehicles and aircraft could not be manufactured, sold or even repaired in the EU without the use of fluoropolymers. Fluoropolymers are used in hundreds of individual components, offering excellent durability under harsh operating conditions and ensuring safe and efficient operation of the vehicle. Cars and aircraft are complex vehicles with thousands of individual parts and components, all of which must meet very strict performance and safety specifications. This performance must be maintained over decades of operating life of the vehicle. The current car and aircraft designs are offering the highest possible performance and safety with the help of fluoropolymers in most of their components. Fluoropolymers have been used in vehicles and aircraft for many decades and are part of their design. To maintain the performance and safety of a vehicle or craft throughout their long service life, OEMs and OVMs must supply spare parts for several years after the end of serial production. Depending on the contract, this can be as long as 10 or 15 years, and maybe even longer for aircraft, which have lifetimes of several decades. If fluoropolymers cannot be used in these spare parts anymore, it can mean that cars may not be able to be serviced properly or use lower performing unauthorised spare parts. Aircraft, which are required to use only authorised spare parts, could not be serviced or repaired at all until non-fluoropolymer parts could be designed and approved, after they run out of the supply of existing fluoropolymer spare parts. This process takes several years after validation of the alternative. In addition, airline operators are obliged to ensure the airworthiness of their fleet before every flight, as per Regulation (EU) 2018/1139 on common rules in the field of civil aviation [...]¹⁷. If it is not possible to have (or easily procure) the necessary (fluoropolymer) spare parts or subsystems to maintain or repair the aircraft at every airport, guaranteeing airworthiness may not be possible. Carrying out maintenance operations only in non-EEA locations carries a huge risk and may not even be possible for the majority of the smaller, regional airlines. Furthermore, alternative materials have lower performance and higher weight, which would lead to negative effects on safety, fuel consumption and fuel efficiency in vehicles. As a result, vehicles may break down more often (including higher risk for aircraft part failures) or be abandoned for newer ones, leading to greater waste generation and higher raw material and energy consumption, and, therefore, a much worse environmental footprint.

¹⁷ Regulation (EU) 2018/1139 of the European Parliament and of the Council of 4 July 2018 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency, and amending Regulations (EC) No 2111/2005, (EC) No 1008/2008, (EU) No 996/2010, (EU) No 376/2014 and Directives 2014/30/EU and 2014/53/EU of the European Parliament and of the Council, and repealing Regulations (EC) No 552/2004 and (EC) No 216/2008 of the European Parliament and of the Council and Council Regulation (EEC) No 3922/91 (Text with EEA relevance.). Available online at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018R1139>, accessed on 25 August 2023

Use sector	Indicative uses	Benefits from the continued use of fluoropolymers
Chemical processing	Fluid handling systems, Pipes (solid pipes and pipe linings), flue duct expansion joints. Seals, gaskets, valves, fittings, linings, filters, O-rings. PTFE-thread sealing tape. Tanks, lining of reaction vessels. Ion-exchange membranes (e.g., for chloralkali production). Wire and cable coatings for sensors, flowmeter tubes, and other electrical and electronic sensing and control equipment.	The EU is among the largest chemical manufacturing regions in the world, with a total output of almost € 600 billion (corresponding to a 14.7% global market share) and a trade surplus of over € 36 billion in 2021. Fluoropolymers ensure the safe operation of equipment which needs to work continuously under extremely harsh and dangerous conditions with practically no margin for errors. Many key refining and chemical manufacturing processes use fluoropolymers to ensure high efficiency and minimal leakages and loss of materials. High temperature processes, such as those carried out in oil refineries and petrochemical plants, and processes using corrosive agents (acids, bases) benefit from the use of highly durable sealing and lining fluoropolymer components, with longer service life for the equipment and significantly reduced need for maintenance or replacement due to breakdowns. Certain processes also need to be carried out at high temperatures or pressures. In addition, essentially the whole chloralkali industry needs fluoropolymers for their electrolytic cells. Without fluoropolymers, there could be a significant shortage of critical building blocks in the chemical industry, i.e., hydrochloric acid and sodium hydroxide. It must also be noted that chlorine is the chemical most commonly used to disinfect drinking water. Here, it should be noted that the chemicals processing industry is strongly interconnected, with the products from one process used as feedstock in several downstream ones. Therefore, use of fluoropolymers in an upstream process, e.g., in a refinery or a petrochemical plant, supports multiple downstream processes not just in the chemical industry but also in the manufacturing sector. Therefore, the implementation of fluoropolymer components, linings and coatings is essential for the uninterrupted and efficient operation of critical chemical processes in the EU.
Construction	Wire and cable insulation, plenum cable insulation, Architectural protective and decorative coatings (e.g., on bridges), laminates, resistant paints, anti-graffiti and antifouling coatings, surface treatment in natural stone, metal, glass, plastic Bridge and offshore pad bearings Greenhouse films PTFE-thread seal tapes for pipes	Fluoropolymers have several applications in construction, especially as protective materials and coatings, protecting exposed surfaces from the elements and waterproofing structures. They are extremely durable and very light, reducing the load on the construction and protecting it from wear. Fluoropolymers are also flame resistant or completely non-flammable, and can thus reduce the risk of fire, especially in electrical installations. In larger constructions, such as bridges and offshore towers, use of lightweight and very low friction PTFE bearings ensures minimal wear and maintenance, and thus structural integrity throughout their very long lives. Also, use of PTFE-thread tapes, as well as fluoropolymer seals in gas and fuel installations in houses, prevents leakages and potential explosions or other accidents.

Use sector	Indicative uses	Benefits from the continued use of fluoropolymers
Energy, batteries and hydrogen	Solar panel coatings, O-rings, seals, gaskets, proton exchange membranes in fuel cells, in alkaline electrolyzers and for hydrogen production via electrolysis, binder materials in the electrodes, both anode and cathode, and as a component of the gas diffusion layers (GDLs). Infrastructure for transport and storage of hydrogen (lining materials, seals etc.), seals in liquid organic hydrogen carrier technologies. Potentially in turbines in flanged connections in order to mitigate leakages, in power generation using H₂. Binders in electrodes of batteries, separator coatings, additives in the electrolyte, gaskets/seals, pipes, valves and sealings in the battery itself, manufacturing of positive electrodes for Li-ion cells Solar panel and wind turbine blade coatings.	In summary, fluoropolymers offer efficient and economic solutions for safer buildings and constructions with lower need for maintenance and repair. Fluoropolymers are a key enabler for promoting sustainable energy generation, contributing to the EU's climate change and decarbonisation goals for 2030 and 2050. They are key components in established and emerging technologies, and help develop the new energy generation, storage and transport / transmission in the EU in the short- and long-term. Without polymers, development and adoption of hydrogen generation, storage and transport technologies in the EU will be severely constrained, as they are essential components of electrolyzers and electrodes. In addition, they can be used as high-performance seals and linings in hydrogen transport and storage equipment. Hydrogen is a very elusive, and highly flammable gas, so containing any potential leaks is essential for the safety of personnel and equipment. Use of batteries for EV and storage of energy from renewable energy sources (RES), which do not always produce during peak electricity demand, is expected to rise sharply in the EU until 2030 and beyond. Fluoropolymers are also a key material for batteries, allowing for long lifetimes without need for replacement, thus also contributing to reduced (critical) raw material usage. Established RES also use fluoropolymers as protective coatings to ensure low wear and reduced need for maintenance, as well as for lubrication. For example, PFPE can be used as lubricant in difficult to reach wind turbines, as it requires less frequent maintenance. Even conventional power generation facilities, including nuclear use fluoropolymer seals and wire jacketing to mitigate leakages and increase efficiency in their operations. In summary, fluoropolymers are essential for the present and the future of energy generation, storage and transmission in the EU. Without these materials, the overall carbon footprint of the EU power generation would be much higher and the EU's climate change and decarbonisation goals would be jeopardised. The proposed broad derogation for all uses of fluoropolymers in petroleum and mining applications highlights the importance of the materials for the sector. Fluoropolymers ensure the safe operation of equipment which needs to work continuously under extremely harsh and dangerous conditions with practically no margin for errors. However, the limited duration of the derogation puts the long-term safety and performance of equipment in these applications at risk, as identification of technically feasible alternatives even in the long derogation period proposed is very uncertain.
Petroleum and mining	Chemical resistant components (e.g., seals) and coatings for extraction, transport and processing of petroleum and ores. Wire and cable insulation and covering Coating for sensors	

Use sector	Indicative uses	Benefits from the continued use of fluoropolymers
		Fluoropolymers are thus essential for a foundational industry sector providing the EU with necessary raw materials that strengthen its independence for supply of critical raw materials and oil and gas.
Food contact materials and packaging	Industrial, commercial and consumer cookware and bakeware Water and oil-repellent coating on paper products and packaging (cans, bags, etc.) Conveyor belts for cooking and drying foodstuff Extrusion and processing aids for plastic film production Process lubricants	As mentioned in Annex E to the PFAS restriction proposal (Section E.2.3.4.3), fluoropolymers are widely used in the food and feed processing industry, with practically all almost 300,000 companies (of which 99% are SMEs) using fluoropolymers at some stage in their processing facilities, as coatings, seals or food handling equipment. Fluoropolymers minimise the risk of contamination and enable easy cleaning of processing lines, vessels and piping. It can be therefore said that without fluoropolymers, the production output and the quality, if not the safety, of food and feed produced in the EU would be at risk.
Electronics and semiconductors	Components of electronic devices (e.g., Hard disk drives), Semiconductor manufacturing (e.g., HEPA filters, wet processing equipment components) O-rings, seals, gaskets, parts and tubing used in the semiconductor processing industry, Welding and soldering agent, Insulation in wires and cables, Coatings, batteries and smart devices Powder coating for phone and tablet screens. Anti-reflective coatings for semiconductors Sensor applications (industrial, automotive, measuring and analytical)	Digitalisation is among the main goals of the EU, and will contribute to strengthening the EU industry, power generation and transmission, and towards the EU's climate goals, among other benefits. Technology has also been becoming increasingly more elaborate and “smart” electrical equipment is available in more and more aspects of everyday life, but also in commercial and industrial environments. All these are enabled by the use of semiconductor chips, which are becoming increasingly sophisticated and miniaturised. Semiconductors have been among the largest drivers to increase productivity and quality of products in the EU. The EU has recognised their importance and plans to strengthen its position in the global market and increase its technological independence, with the European Chip Act, which was approved by the EU Parliament in July 2023. Manufacturing of semiconductors would not be possible without the use of fluoropolymers, which are used in all phases of fabrication and are also used in chip packaging.
Water and wastewater treatment	Hollow fibre micro- and ultra-filtration water & wastewater treatment membranes Water piping	Fluoropolymers and semiconductor chips are also used directly on the electrical and electronic equipment practically across all sectors of the economy and all levels of society, increasing durability of sensitive equipment and prolonging their lifetime. They are, therefore, a significant enabler of lower waste generation and critical raw material usage in the EEE sector, as they contribute to more resilient equipment. Fluoropolymer (PVDF) membranes have been used for decades in a broad range of water treatment applications in the EU, including wastewater and drinking water applications. Their durability against aggressive contaminants in the treated water make them the material of choice in demanding applications. Drinking water treatment is subject to very high quality and cleanliness specifications in terms of e.g., organic content, metals content, removal of pathogens, etc. Municipal water plants vary in size, depending

Use sector	Indicative uses	Benefits from the continued use of fluoropolymers
		on the size of the community they serve, with the larger ones serving more than a million people in major EU cities and agglomerations. These treatment plants are designed to operate for decades, during which time they will undergo changes in capacity, treatment methods and efficiency targets arising from new regulations. Similarly, wastewater treatment plants are designed and built on limited space, which needs to take into consideration potential expansion of capacity. In both cases, fluoropolymer membranes are more efficient and can offer better removal of contaminants and pathogens than alternatives, at a smaller volume and with longer lifetime. Therefore, they contribute to both reduced construction and operating costs, as the facilities can have a smaller footprint and require less maintenance and replacement. The amount of fluoropolymer membranes sold in Europe in 2021 for potable water, wastewater and industrial water treatment was approximately 7.9 million m², while the surface area of fluoropolymer membranes currently in use in Europe is estimated at 10.2 million m², which is sufficient to service the equivalent of 159 million households (assuming a flux of 65 litres per m² per hour and typical usage of 100 litres per day per household.) This number is expected to increase significantly in the near and mid-term, as the ultrafiltration market is expected to exhibit strong growth with a CAGR of approximately 5.9%¹⁸. Fluoropolymers are also important in water piping, where their high durability and very good fitting prevents leakages and minimises the need for repair or replacement, thus reducing costs for both consumers and the operators / municipalities. In addition, they preserve water, which is an increasingly important resource in the EU, especially considering the increasing impacts of climate change, with warmer temperatures and more severe droughts.
Lubricants	High performance lubricants (stable and inert) for applications in the aerospace, military, automotive, electronics, semiconductor, textile, chemical, paper, plastic and nuclear industries. High performance lubricants for engines and machinery.	Fluoropolymer lubricants (mainly PTFE and PFPE) are used across the industry spectrum in the EU, maintaining high performing equipment such as cars and aircraft, as well as vacuum pumps in the chemical, food processing and manufacturing industries, among others. They are among the best performing lubricants in applications where durability and stability at a broad range of extreme conditions (temperature, pressure, corrosive agents) are required, and, in some cases, they are the only option available to meet the strict industry and regulatory requirements.

¹⁸ BCC Research website – Ultrafiltration membranes: Technologies and global markets. Available online at: <https://www.bccresearch.com/market-research/membrane-and-separation-technology/ultrafiltration-membranes-techs-markets-report.html>, accessed on 25 August 2023

Use sector	Indicative uses	Benefits from the continued use of fluoropolymers
	Lubrication for vacuum pumps, high-pressure oxygen equipment. Non-stick coatings as dry film lubricants in baked goods production, food processing, automotive and transportation, high-temperature kitchen equipment, medical equipment.	In addition, their durability makes them excellent for use in remote locations, such as in wind turbines or photovoltaic installations, leading to lower maintenance and repair needs. Use of lower performing lubricants could lead to worse performance of equipment and vehicles and could lead to higher rates of breakdowns and need for maintenance and replacement.
Medical devices and pharmaceuticals	Biomedical devices Other medical devices, e.g., catheters, stents, heart patches, sutures, seals, lubricants, filters or surface treatment Coating in primary packaging components, coating for metered dose inhalers Analytical equipment and laboratory applications.	Use of fluoropolymers in the medical device and pharmaceutical sectors is very extensive and ranges from coatings on invasive and non-invasive medical devices and packaging, to sealing and wires used in analytical and IVD instruments, to filters and other components in manufacturing operations where high cleanliness conditions are required. The medical device industry in the EU is among the most innovative ones worldwide and offers patients globally a range of products that enable advanced treatment for acute and chronic health conditions. Their use is becoming increasingly important, especially considering the aging of the EU population and the increased need for operations, invasive or not. In addition, the analytical equipment used in diagnosis and monitoring of patients' health uses fluoropolymer coatings and components to perform its operations with precision. The IVD industry has developed very sophisticated and accurate solutions that allow doctors to make quick and informed decisions for each patient. Apart from the applications explicitly mentioned in the proposed and considered derogations, medical equipment using fluoropolymers include endoscopy and other monitoring / sensor equipment, which need miniaturised wires with fluoropolymer jackets. Overall, use of fluoropolymers in the pharmaceutical and medical device industry enables the development and application of innovative, advanced diagnostic, treatment and monitoring methods, that improve the quality of medical services offered to patients in the EU and worldwide.
TULAC	Waterproof and stain repellent clothing Chemical resistant PPE, fabrics, and high-performance textiles Membranes used as filtering media in applications with very low contamination tolerance (e.g., semi-conductors, pharmaceuticals, medical devices, chemical processing)	Benefits from the use of fluoropolymers in the textile and clothing sector can be seen in two aspects. Firstly, professional textiles, not just PPE, that require water and / or oil repellence are more durable and efficient, offering greater protection over their expected long service life. With higher durability, they contribute to lower generation of waste and material use. Secondly, technical and industrial fabrics are essential, e.g., as filters or separation media, for applications with low contamination tolerance and where cleanliness of the fabrication / manufacturing environment are of utmost importance. Fluoropolymer filters are used across several key EU industry sectors, such as

Use sector	Indicative uses	Benefits from the continued use of fluoropolymers
	Coated fabrics for architectural applications, tents and furniture	semiconductors, (bio)pharmaceuticals, medical devices (including IVDs) and some fine chemical manufacturing processes.
Metal plating and manufacturing of metal products	Noise suppression, anti-foam agent Electrical insulation and sealing in metal heating processes. Noise reduction and as dry bearings in metal product manufacturing processes.	

Overall, the benefits from the use of fluoropolymers to the EU society can be summarised in the following points:

- They enable the development and availability of innovative technologies in all sectors of the economy, such as semiconductors used in an increasing range of equipment, including (electric) vehicles, technologies for green energy generation, transport and storage, and
- They increase safety in equipment and products used by industry, professionals and consumers, such as vehicles, aircraft, gas and electricity installations in buildings, and medical equipment. This safety is relevant to both human health and the environment as the equipment is critical in preventing emissions of hazardous chemicals or of chemicals that could cause potentially catastrophic product failure.
- They provide extremely durable components and coatings used in a range of extreme, harsh conditions, minimising the risk of breakdowns and the need for replacement, thus contributing to lower waste generation and lower consumption of often-critical raw materials.

4.3.3 Wider EU societal impacts

As shown in Table 4.6, fluoropolymer applications are central to the realisation of major goals set by EU strategies, such as the European Green Deal, the Critical Raw Materials Act and the EU's Digital Strategy. The industries, sectors and technologies that rely on fluoropolymers are among the key enablers of the EU's strategic goals.

The following sections provide a brief overview of the importance of fluoropolymers in some of the EU's core environmental and technology strategies.

4.3.3.1 EU Green Deal

The EU Green Deal was first presented in December 2019 and since then has driven the development of a comprehensive set of strategies for all environmental aspects and economic sectors. Its strategies aim at pushing the EU into a more sustainable and greener future, without impairing the competitiveness and innovation of the European economy.

The Green Deal aims to improve the well-being and health of citizens and future generations by providing¹⁹:

- fresh air, clean water, healthy soil and biodiversity
- renovated, energy efficient buildings
- healthy and affordable food
- more public transport
- cleaner energy and cutting-edge clean technological innovation
- longer lasting products that can be repaired, recycled and re-used
- future-proof jobs and skills training for the transition
- globally competitive and resilient industry

More specifically, among the central goals of the EU Green Deal are:

- A commitment for the EU to become carbon neutral by 2050, supported by increased use of renewable energy sources (such as onshore and offshore wind turbines and photovoltaics) in power generation, in industry and in transportation. As part of this policy, the EU has issued a series of proposals to revise and update EU legislation (the Fit for 55 package). This includes a target of 40% contribution of Renewable Energy Sources (RES) to energy generation. This target has been subsequently revised upwards to 45%, as a result of the REPowerEU initiative.

¹⁹ https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

- The REPowerEU plan was introduced by the European Commission aiming to reduce its reliance on imported oil and natural gas from Russia and at increasing the EU's energy independence²⁰.
- Investment in developing clean hydrogen production capacity, to be used as feedstock, fuel and energy carrier and storage²¹.
- A 90% reduction in greenhouse gas emissions in transport by 2050, enabled by the adoption of electric vehicles (EV), with a goal of 30 million zero-emission cars and 80,000 zero-emission lorries on the streets by 2030²².

Fluoropolymers are instrumental in achieving those strategic goals, as they are essential for many of the technologies and applications that are crucial to the EU meeting those goals:

- Fluoropolymers are used as a binder in Li-ion batteries, offering extended lifetime and performance over a broad range of conditions. Those batteries are the central component of EV and their use is expected to increase significantly until 2030 and beyond. Alternative technologies have much lower durability than fluoropolymers and will need several years of development before they can be considered as a replacement. Energy storage (e.g., from RES, which do not always produce energy during peak demand hours) is another use for batteries expected to contribute to the EU's decarbonisation goals.
- Fluoropolymers, in particular fluorinated ionomers, are a key enabling material for several hydrogen technologies, including electrolysis membranes, electrodes, as well as sealing and lining equipment for hydrogen storage and transport equipment. Electrolysis and fuel cell membranes from alternative materials have a much lower lifetime than fluoropolymer ones and cannot be considered as suitable alternatives for such applications.
- Other RES, such as wind turbines and photovoltaics, also rely on the use of fluoropolymers. Base bearings in onshore and offshore wind turbines, and photovoltaic installations are often PTFE, due to the fluoroplastic's very low coefficient of friction, allowing for more efficient designs with lower need for maintenance and wear. Fluoropolymer coatings and cable / wire jacketing and insulation, as well as lubricants, are also used in installations exposed to harsh conditions, such as for offshore wind farms.
- Fluoropolymer coatings are also used on wind turbine blades and photovoltaic panels to offer water and oil repellence and protect them from wear and corrosion, thus ensuring their efficient performance throughout their long service life.
- Seals for valves and pumps, and coatings for conventional power stations also ensure that they can operate at higher temperatures and with fewer losses, enabling more efficient power generation and reduced fuel consumption.

4.3.3.2 *European Chips Act*

On July 11, 2023, the EU Parliament voted in favour of the adoption of the EU Chips Act, which aims at boosting the EU's technological independence, competitiveness and resilience, and also contributes to the EU's digital and green transitions (i.e., EU Green Deal).

The European Chips Act stems from the recent chips shortage, which has disrupted some supply chains relying on them, such as the automotive, communications and machinery industries. To ensure resilience of the EU

²⁰ European Commission press release. REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition. 18 May 2022. Available online at: https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131, accessed on 21 August 2023

²¹ European Commission (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, on A hydrogen strategy for a climate-neutral Europe. COM(2020) 301 final. Available online at: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0301>, accessed on 21 August 2023

²² European Commission (2020). Factsheet – The transport and mobility sector. Available online at: https://ec.europa.eu/commission/presscorner/detail/en/fs_20_2350, accessed on 21 August 2023.

industry, the European Chips Act aims at increasing the EU's market share in semiconductors to 20% globally by 2030 (currently it is 10%)²³ and includes a policy-driven investment package worth €43 billion until 2030²⁴.

The semiconductor industry is a primary focus of this initiative and fluoropolymers are essential both in the fabrication stage, e.g., as filters or equipment linings and coatings, and in the packaged chips sold to customers. Continued use of fluoropolymers will thus enable a strong growth for the EU chip manufacturing industry in the mid- and long-term.

4.3.3.3 *European Critical Raw Materials Act*

The European Critical Raw Materials Act is a set of actions intended to secure the EU's access to a diversified, affordable and sustainable supply of critical raw materials. It is expected that the EU's demand for certain critical and strategic raw materials, such as lithium, is expected to increase significantly in the coming years as a result of increased adoption of technologies such as electric vehicles and advanced electronics, including semiconductors (as per the targets of the European Chips Act, and the Net Zero Industry Act, for example).

Fluoropolymers are durable and stable against extreme conditions such as temperature, pressure, and corrosive or reactive chemicals. As a result, they reduce wear in various equipment they are used in. Furthermore, they protect the equipment from conditions such as moisture, oils or other chemicals, which can damage the equipment. The equipment can thus operate for a long time with low chance of failure or breakdown and little need for maintenance or replacement with the corresponding energy and raw material needs.

In conclusion, use of fluoropolymers improves the durability of the equipment in which it is used and reduces the generation of waste and consumption of often-critical raw materials and energy resources.

4.3.4 *Summary of impacts in a limited derogation scenario*

If use of fluoropolymers is not allowed under a limited derogation scenario, impacts to the society will be disproportionate to any benefits.

- Fluoropolymers support essential downstream operations worth hundreds of billions of euros in the EU, including some of the largest manufacturing sectors in the region, such as automotive, aerospace, chemical and medical technology industries. It is estimated that these sectors employ tens of millions of people in the EU and a large share of these jobs may be at risk under this scenario.
- The total value of fluoropolymer products manufactured or sold in the EU by FPG members participating in this study was estimated to be in the range of €1.0 – 3.0 billion in 2022. This value will be lost and is unlikely to be transferred to suppliers / manufacturers of alternatives in the EU, considering the difficulty in identifying and implementing suitable alternatives for most of the demanding applications in which fluoropolymers are used.
- Many downstream manufacturing sectors in the EU will also be impacted if they are not allowed to use fluoropolymers in their manufacturing processes, and all that is required for manufacturing at a site such as technical components, pipe linings etc. The downstream impacts are much greater than the impacts for the manufacturers. The value of products relying on the use of fluoropolymers in these sectors was estimated between € 900 and €1,400 billion in 2021 with the available information in this study, and it is expected that it will increase in the near future, as new technologies that need fluoropolymers are expected to increase in importance in the EU.
- Many technologies and products that are currently taken for granted in the EU may cease being available, just because they contain a fluoropolymer component or coating. These can include advanced electronic equipment, such as “smart” devices. In addition, adoption of emerging technologies, such as electric

²³ European Commission website – European Chips Act. Available online at: <https://digital-strategy.ec.europa.eu/en/policies/european-chips-act>, accessed on 21 August 2023.

²⁴ European Commission website – A Europe fit for the digital age. Available online at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age_en, accessed on 21 August 2023.

vehicles, may be severely hampered, as they need fluoropolymers to perform according to their specifications, including, for example, passenger safety specifications.

- In some cases, if the downstream users decide to use non-fluorinated alternatives (if available at all), the overall performance of the product, e.g., fuel efficiency in vehicles, and breakdown rates on devices and vehicles / aircraft, may be worse. This could lead to a higher frequency of failures and breakdowns, with more need for maintenance and replacements. The result could be increased waste generation and higher raw material usage, which are against the EU's goals towards a more circular economy and reduced use of critical raw materials. This can be particularly important for products relying on the supply of strategic and critical raw materials, such as the lithium used in batteries.
- Fluoropolymers are an important contributor to safety in various aspects of the economy in the different value chains in which they are used. Preventing leaks of hazardous and potentially flammable or explosive chemicals minimises the safety risks that could arise, such as explosions, fires or health issues for workers and the local communities.
- Fluoropolymers are critical for the EU meeting the goals of its new Green Deal, in particular with regards to climate change and decarbonisation, and circular economy and sustainable use of (critical) raw materials. They are essential for the development of key technologies, such as green hydrogen generation and electric vehicles.

5. CONCLUSIONS ON THE IMPORTANCE OF FLUOROPOLYMERS

This report has presented that the benefits to the EEA society enabled by the use of fluoropolymers in a broad range of critical industry sectors are manifold. Advanced technologies and products in medical devices, transportation, energy and electrical and electronic devices would not be possible without fluoropolymer components and coatings. In addition, critical (petro)chemical, pharmaceutical and other manufacturing processes can be operated safely and reliably thanks to fluoropolymer equipment, such as sealings, pipe linings, and filtering / separation membranes.

Fluoropolymers also enable the development of technologies that contribute to the EU's decarbonisation goals and circular economy, as set forth in the EU Green Deal. Technologies such as electric vehicles, smart electricity grids and hydrogen would be pushed back several years if use of fluoropolymers is banned in the EU. They are also essential in maintaining strategic autonomy in many critical sectors of the economy, such as medical devices, transportation and aerospace, energy and semiconductors.

Overall, a limited derogation scenario could result in significant impacts not just for the fluoropolymer manufacturers, but for the whole EEA economy and society. These important functions of fluoropolymers should therefore be taken into consideration for an extended derogation for fluoropolymers.



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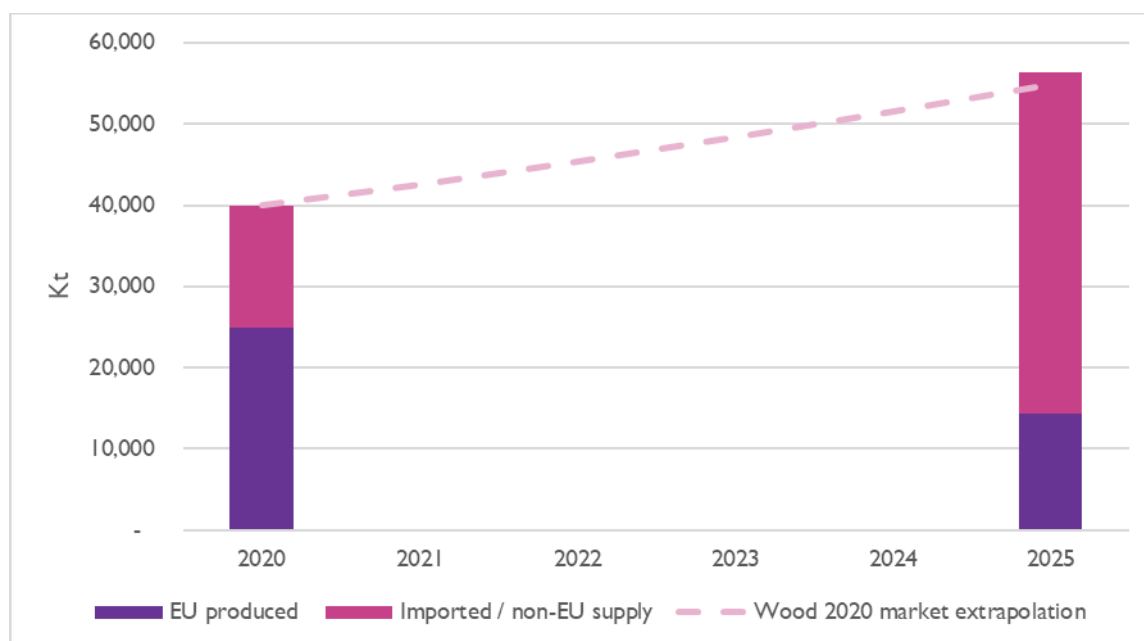
Executive summary

Fluoropolymers are small-volume, high-performance materials that play enabling roles across strategically important EU value chains. They are used in applications where chemical resistance, thermal stability, durability, electrical performance and reliability are critical, including defence, transport, clean energy technologies, semiconductors, electronics, sealings, lubricants, medical and pharmaceutical-related applications and wider industrial uses.

This report assesses the socio-economic importance of fluoropolymers from two complementary perspectives. First, it estimates the economic footprint of fluoropolymer manufacturing within the EU27. Second, it assesses the scale of downstream economic activity that may be exposed where fluoropolymers perform enabling functions and substitution is difficult or not viable in the short run.

EU27 fluoropolymer demand is materially larger than EU27 domestic supply. The report estimates the EU27 fluoropolymer market at approximately 56,500 tonnes in 2025. Domestic manufacturers produced approximately 29,500 tonnes of fluoropolymers in the EU27 and exported approximately 15,000 tonnes, implying that around 14,500 tonnes of EU27-produced fluoropolymers were supplied to the EU27 market. Comtrade data indicate imports of approximately 42,000 tonnes, indicating EU27 production accounts for approximately one quarter of EU27 fluoropolymer market supply, with imports or non-EU supply accounting for approximately three quarters. Previous estimates indicate that imports accounted for around 38 per cent of fluoropolymers sold in the EU28/EEA in 2020, suggesting that over the last five years import dependence has increased substantially.

Figure 0.1: Indicative change in European fluoropolymer market supply structure, 2020–2025



2020 figures are based on Wood's estimate of fluoropolymers sold in the EU28/EEA, split between EU-produced supply and imports. The 2025 figures are based on the central market estimate used in this report and producer data collected for this study. The dotted line shows an extrapolation of Wood's 2020 market estimate using the annual growth assumption referenced in the Wood analysis; it is included as an indicative trend rather than an observed market series.

Table 0.1: Estimated EU27 fluoropolymer market size and structure, 2025

Quantities (tonnes)	EU27
Tonnes produced in the EU27	29,500
Tonnes imported into the EU27	42,000
Tonnes exported from the EU27	15,000
EU27-produced supply sold in the EU27	14,500
Tonnes sold in the EU27	56,500
Implied share of EU sales supplied by EU	25%
Implied share of EU sales supplied by non-EU	75%

Figures are rounded to the nearest 500 tonnes. Shares are calculated using unrounded figures where available and rounded to the nearest whole percentage point. Comtrade imports refer to EU imports reported under HS 390461 and HS 390469 in 2025. HS 390461 covers polytetrafluoroethylene in primary forms, while HS 390469 covers other fluoropolymers in primary forms.

EU fluoropolymer manufacturing supports wider EU economic activity. EU27 fluoropolymer manufacturing directly supports approximately **€620 million of output, €150 million of GVA** and **2,800 FTE jobs**. Once indirect and induced effects are included, the estimated economy-wide footprint rises to approximately **€1.6 billion of output, €550 million of GVA** and **14,500 FTE jobs**.

These wider effects arise because fluoropolymer manufacturing is embedded in EU supply chains. Production generates upstream demand for chemicals, utilities, refined petroleum products, logistics, wholesale trade and professional services. The sector also supports induced activity through wage spending associated with direct and indirect employment.

Table 0.2: Economic footprint of EU27 fluoropolymer manufacturing, 2025

	Output	GVA	Employment
Direct footprint	€620m	€150m	2,800 FTE
Total footprint, including indirect and induced effects	€1.6bn	€550m	14,500 FTE

Fluoropolymers enable downstream sectors far larger than the fluoropolymer market itself.

The economic importance of fluoropolymers cannot be assessed by reference to fluoropolymer sales alone. In many applications, fluoropolymers account for a small share of input value but perform functions that are critical to downstream product performance, reliability, durability or compliance.

The report therefore assesses downstream value at risk in selected fluoropolymer-dependent applications. Due to practical constraints and data availability, the quantified analysis focuses on transport, energy and sealings. These areas were selected because they are economically material, strategically relevant and could be mapped to downstream economic data with sufficient robustness for quantified analysis. These are not the only relevant sectors or applications: fluoropolymers are also used in many other areas such as semiconductors, electronics, construction, medical applications and broader industrial uses. The analysis is therefore an exposure assessment for selected applications, not a comprehensive quantification of all downstream activity linked to fluoropolymers. It is not a forecast of losses, but an estimate of the scale of downstream activity associated with applications where fluoropolymers perform enabling functions and where substitution may be difficult or not viable in the short run.

Under the baseline no-derogation scenario, fluoropolymer applications are associated with approximately:

- €330 billion of transport output, €77 billion of GVA and 727,100 FTE jobs exposed;
- €9.0 billion of energy-related output, €2.9 billion of GVA and 25,000 FTE jobs exposed; and
- €20 billion of sealing-related output, €5.1 billion of GVA and 54,900 FTE jobs exposed.

The report also assesses the implications of a derogation-based approach. The main-case assumptions are that 50 per cent of relevant transport fluoropolymer sales value remains restricted, 90 per cent of relevant energy sales value remains restricted, and 100 per cent of relevant sealing sales value remains restricted.

These assumptions reflect the relatively narrow or uncertain coverage of the derogation framework, especially for cross-cutting and energy-related applications.

Applying these assumptions to the central baseline value-at-risk estimates indicates that material downstream activity could remain exposed even after derogations are taken into account. The derogation-adjusted estimates are approximately:

- €165 billion of transport output, €39 billion of GVA and 364,000 FTE jobs;
- €8.1 billion of energy-related output, €2.6 billion of GVA and 22,500 FTE jobs; and
- €20 billion of sealing-related output, €5.1 billion of GVA and 54,900 FTE jobs.

Table 0.3: Downstream value-at-risk estimates

Area	Central baseline output at risk	Residual restricted share	Derogation-adjusted output at risk	Derogation-adjusted GVA at risk	Derogation-adjusted employment at risk
Transport	€330bn	50%	€165bn	€39bn	364,000 FTE
Energy	€9.0bn	90%	€8.1bn	€2.6bn	22,500 FTE
Sealings	€20bn	100%	€20bn	€5.1bn	54,900 FTE

Sealings are a cross-cutting application category and should be interpreted alongside, rather than added mechanically to, the transport and energy estimates. The figures are measures of exposure, not forecasts of losses.

The strategic issue is not only whether selected end uses are exempted or derogated. It is whether the derogation framework preserves enough aggregate demand to sustain viable EU fluoropolymer production.

Some strategic uses, particularly defence, may account for relatively small fluoropolymer volumes but have high strategic importance, especially in the context of the EU's growing focus on security, resilience and strategic autonomy. The same applies to other critical sectors, including medical, aerospace, semiconductors and clean technologies. However, these volumes may not be sufficient on their own to sustain EU production capacity. Fluoropolymer manufacturing involves specialised assets, technical know-how, regulatory obligations and fixed costs. Stakeholders therefore argue that production viability depends on demand across a wider portfolio of applications, including transversal uses such as sealings and lubricants.

If restrictions remove a substantial share of this wider demand base, EU production could become less viable even where selected strategic uses are formally derogated. In that case, a derogation for defence or other critical applications may be of limited practical value if the EU production base needed to supply those applications is weakened or lost.

The resulting risk is increased dependence on non-EU supply chains. Depending on the final scope and enforcement of the restriction, this could mean greater reliance on imported fluoropolymers, imported fluoropolymer-containing components, or finished and semi-finished goods produced outside the EU using fluoropolymer inputs. This would run counter to EU objectives on industrial resilience, economic security, clean technology deployment and strategic autonomy.

Overall, the analysis shows that fluoropolymers should be assessed as enabling inputs within wider industrial value chains, not only by reference to their direct sales value. The proportionality assessment should therefore consider the combined effect of restrictions on EU manufacturing capability, import dependence, downstream exposure and the viability of supplying strategic uses under a narrow derogation framework.

1 Introduction

1.1 Policy context

The European Union is currently considering a broad restriction on per- and polyfluoroalkyl substances (PFAS) under the REACH Regulation, including the possible use of derogations for certain substances or applications. Within this process, fluoropolymers have emerged as a distinct category due to their role in critical industrial applications, their contribution to strategic value chains and the limited availability of technically and economically viable substitutes in many uses.

The Fluoropolymers Product Group (FPG) supports the view that fluoropolymers are critical to the resilience of the European industrial base and should therefore be exempted from the proposed restriction. The FPG also argues that the design of any derogations is important. If derogations are limited to selected fluoropolymers or narrowly defined applications, EU manufacturers may not be able to maintain the scale of production needed to operate viably in Europe.

In particular, the policy debate has focused on the role of fluoropolymers in supporting sectors linked to EU competitiveness, strategic autonomy and critical technologies, including semiconductors, clean energy, electronics, medical, defence, aerospace and automotive manufacturing. In the view of the FPG, these sectors (which include sectors widely recognised as having a strategic or security dimension) depend not only on access to individual fluoropolymers for specific applications, but also on the continued presence of a functioning European fluoropolymer manufacturing base.

A central issue within the debate therefore concerns the resilience and continuity of fluoropolymer supply within Europe. Demand for fluoropolymers in strategic applications is increasing while EU production capacity is under pressure, creating a growing reliance on imports and exposing downstream industries to potential supply-chain vulnerabilities. If restrictions or narrowly scoped derogations reduce the viability of EU production, this could further increase dependence on non-EU supply, which in the view of the FPG would weaken industrial resilience, increase exposure to supply disruptions and undermine the EU's strategic autonomy in critical technologies.

Within this context, the socio-economic assessment focuses not only on the direct economic contribution of fluoropolymer manufacturing, but also on the broader role fluoropolymers play in supporting downstream industrial activity, maintaining viable manufacturing capability within Europe and contributing to wider economic resilience.

1.2 Purpose of this report

Europe Economics was commissioned by the Fluoropolymers Product Group (FPG) of Plastics Europe to collect, aggregate and assess socio-economic evidence relating to fluoropolymer manufacturing in Europe in support of the European Chemicals Agency (ECHA) Socio-Economic Assessment Committee (SEAC) consultation regarding the proposed PFAS restriction.

The purpose of this report is to quantify the economic footprint of fluoropolymer manufacturing within the EU and assess its role in downstream industrial activity and strategic value chains. The analysis combines aggregated manufacturer data with publicly available economic data to estimate direct, indirect and induced economic impacts, assess supply dependence and external trade position, and map fluoropolymer supply to downstream sectors.

The analysis is intended to support assessment of the economic significance of fluoropolymers within the European economy, including their contribution to industrial activity, supply-chain resilience and strategic sectors linked to critical technologies. In line with the project scope, the assessment focuses on fluoropolymer manufacturing activity rather than direct evidence collection from downstream users, which are providing separate inputs within the wider SEAC consultation process.

2 Analytical approach

This chapter sets out the data sources and methodology used to estimate the economic footprint of EU fluoropolymer manufacturing and the downstream value potentially at risk under restriction scenarios.

The analysis is designed to be proportionate and transparent. It focuses on the two central economic questions addressed in this report: first, the scale of economic activity supported by EU fluoropolymer manufacturing; and second, the extent to which downstream sectors may be exposed if fluoropolymer supply is restricted. The methodology reflects the practical constraint that fluoropolymers are not separately identified in official input-output statistics.

2.1 Data

The approach combines manufacturing data provided by members of Plastics Europe with public datasets, including Eurostat input-output tables, to develop estimates of wider economic activity and downstream exposure.

2.1.1 Manufacturer data

The primary input to the analysis is a consolidated dataset compiled from information provided by seven EU fluoropolymer producers, which are understood to account for all major fluoropolymer production within the EU27. The dataset therefore provides a robust basis for estimating the economic footprint of EU27 fluoropolymer manufacturing.

The dataset should not, however, be interpreted as a complete measure of the total fluoropolymer market supplied to EU downstream users. The EU market is also supplied by imports from producers outside the EU27. For this reason, the report separately considers the size and supply structure of the European fluoropolymer market in Section 3.1.

The manufacturer dataset includes information on fluoropolymer production, sales and employment. These data provide the basis for estimating the direct economic footprint of EU fluoropolymer manufacturing. Where available, producer data have also been used to allocate sales by downstream application or sector, using categories aligned with the ECHA sector mapping and the wider socio-economic assessment framework. Manufacturers were also asked to provide more detailed mapping for three priority areas: transport, energy and sealings. This additional mapping was used to support the downstream value-at-risk assessment, particularly where ECHA categories describe cross-cutting application groups rather than final downstream sectors.

The manufacturer data are commercially sensitive, and the analysis therefore applies aggregation and confidentiality principles to ensure that no company-level information is disclosed in the report. For the sectoral and downstream analyses, results are only reported where they are based on data from at least three manufacturers. Where fewer than three manufacturers contribute to a result, or where a result could otherwise risk revealing the position of an individual producer, the result is suppressed or combined with other categories. All results are reported in rounded form to further preserve confidentiality.

2.1.2 Eurostat I-O tables

Eurostat input-output tables are used to estimate the wider economic footprint of EU fluoropolymer manufacturing. These tables describe inter-industry relationships within the economy, showing how output

from one sector is used as an input by others. They therefore provide a basis for estimating indirect supply-chain effects and induced effects associated with household spending. The most recently published Eurostat I-O tables for the EU27 are from 2023.

Fluoropolymer manufacturing is not separately identified in the input-output framework. The analysis therefore uses the closest available sector proxy, chemicals and chemical products,¹ to estimate wider economy effects from the direct output reported by manufacturers.

2.1.3 Eurostat Structural Business Statistics

Eurostat Structural Business Statistics (SBS) are used to estimate sector-level output, GVA and employment for downstream activities. SBS data provide the main public economic denominators for sectors where fluoropolymer applications can be mapped to NACE industrial classifications, such as transport manufacturing.

SBS data are also used to derive GVA-to-output and employment-to-output ratios. These ratios are applied where the downstream denominator is based on PRODCOM product-level production values, which do not include GVA or employment measures.

PRODCOM data are also used as the main source for estimating the economic scale of several downstream fluoropolymer-using sectors, where relevant fluoropolymer applications can be linked to specific product categories. In this context, PRODCOM provides more targeted estimates than broad sector-level data, although the estimates capture sold production rather than total market size including imports.

2.1.4 Eurostat NACE construction data

Eurostat NACE data are used only for the construction sector estimate in the assessment of the economic scale of downstream fluoropolymer-using sectors. NACE is used instead of PRODCOM or SBS data because it classifies economic activity by industry rather than by product, making it more appropriate for capturing construction as a sector-level activity.

2.1.5 PRODCOM production data

PRODCOM data are used where product-level production values provide a more targeted measure of downstream activity than broad sector-level SBS data, or where the relevant SBS sector is confidential. PRODCOM reports production values for specific manufactured products, rather than output, GVA and employment by industrial sector.

In the downstream value-at-risk assessment, PRODCOM data are used for selected energy and semiconductor-related applications. For these applications, PRODCOM sold production values are used as product-level output proxies. GVA and employment are then estimated using ratios derived from the closest available SBS sector.

2.1.6 Comtrade data

UN Comtrade data is used to estimate imports of fluoropolymers to the EU27 market, which informs our market size assessment. We take volumes for 2025 reported under product codes HS 390461 and HS 390469 in 2025. HS 390461 covers polytetrafluoroethylene in primary forms, while HS 390469 covers other fluoropolymers in primary forms.

¹ CPA C20 “Chemicals and Chemical Products”

2.2 Methodology

2.2.1 Economic footprint modelling

The economic footprint analysis estimates the direct, indirect and induced economic activity associated with EU fluoropolymer manufacturing.

The analysis begins with the direct manufacturing footprint, derived from producer-reported information on fluoropolymer production, sales and employment. Direct output is based on the reported sales value of EU-produced fluoropolymers used in the footprint model. Direct employment is based on reported full-time equivalent employment. Direct GVA is estimated using a GVA coefficient derived from the input-output framework. This means that imported fluoropolymers are not included in the direct manufacturing footprint, because they do not generate EU manufacturing output, GVA or upstream supply-chain effects in the same way as domestically produced fluoropolymers. The modelling also does not estimate the smaller EU service-sector activity associated with importing and distributing those fluoropolymers.

To estimate wider economic effects, the analysis applies an input-output framework using Eurostat EU27 input-output tables. Because fluoropolymer manufacturing is not separately identified within official statistical classifications, the activity is represented within the input-output framework using CPA_C20, manufacture of chemicals and chemical products, which is the closest corresponding Eurostat sector classification. Producer-reported fluoropolymer output is treated as an exogenous production shock applied to this sector within the input-output framework.

The model is used to estimate indirect effects, reflecting upstream demand generated through purchases of intermediate goods and services, including chemicals, utilities, transport, wholesale trade and business services. The analysis also estimates induced effects, which reflect additional economic activity supported through household spending associated with wages generated by direct and indirect activity.

Type I multipliers are used to estimate direct and indirect effects. Type II multipliers are used to estimate direct, indirect and induced effects. The total economic footprint is defined as the sum of direct, indirect and induced effects. Impacts are estimated across output, GVA and employment.

2.2.2 Downstream value-at-risk assessment

Scope and analytical approach

The downstream value-at-risk assessment estimates the scale of economic activity potentially exposed to fluoropolymer restrictions under a baseline no-derogation scenario. Specifically, the analysis estimates downstream output, GVA and employment associated with industrial activities in which fluoropolymers play a functionally important role and where substitution may be difficult or not viable in the short run. The analysis is intended to provide an indicative estimate of potential economic exposure across affected downstream value chains rather than a forecast of direct economic losses.

The assessment is based on three producer-data groupings: transport, energy and sealings. The transport and energy submissions were reported as downstream sector groups, while the sealings submissions were reported as a cross-cutting application group covering sealing applications used across transport, energy, semiconductors and other strategic sectors.

The modelling follows three steps. First, manufacturer-reported applications are mapped to downstream sectors or product markets. Second, an activity-share assumption is applied to identify the portion of downstream activity relevant to the fluoropolymer application. Third, a criticality assumption is applied to reflect manufacturer evidence on substitutability.

The core relationship is:

Effective dependency = activity share × criticality

The effective dependency is then applied to the relevant economic denominator:

Output exposed = downstream output denominator × effective dependency

For SBS-led calculations, GVA and employment at risk are calculated by applying the same effective dependency to SBS GVA and employment. For PRODCOM-led calculations, PRODCOM sold production is used as a product-level output proxy, and GVA and employment are estimated using GVA-to-output and employment-to-output ratios from the closest available SBS sector.

2.2.3 Scenario development and estimation approach

Low, central and high scenarios were developed for each downstream subsector or application group. These scenarios reflect uncertainty in both the activity share and criticality assumptions. The activity share captures the proportion of the downstream economic denominator relevant to the fluoropolymer application. The criticality assumption captures the extent to which the relevant activity is materially dependent on fluoropolymers, based primarily on manufacturer evidence on substitutability.

Table 2.1 Scenario Bands Used for Criticality Assumptions

Criticality rating	Range for criticality percentage (%)
Low	0-25
Central	25-75
High	75-100

The combined effective dependency represents the proportion of the downstream denominator treated as exposed in the baseline no-derogation scenario. For example, where a broad sector denominator is used, the activity share may be low even if criticality is high, because only part of the sector is relevant to the fluoropolymer application. Conversely, where a product-specific PRODCOM denominator is used, the activity share may be high because the product category is already closely aligned with the application.

Table 2.2: Activity share and criticality assumptions

Area	Subsector / application	Activity share	Criticality	Effective dependency range
Transport	Road vehicles	Medium	High	15% - 40%
Transport	Rail vehicles	Low to Medium	Medium	1.25% - 18.75%
Transport	Aerospace	Medium	High	15% - 40%
Transport	Maritime / watercraft	Low to Medium	Medium to High	1.25% - 18.75%
Energy	PV	High	Medium	22.5% - 75%
Energy	Hydrogen technologies	Low	High	0.4% - 2%
Energy	Batteries – non-EV / storage	Low	High	3.75% - 20%
Energy	Chlor-alkali membranes	Low	High	7.5% - 30%
Sealings	Transport sealings	Low	High	0.4% - 2%
Sealings	Energy sealings	Low	High	0.4% - 2%
Sealings	Semiconductor sealings	Medium	High	15% - 40%

The ranges are deliberately wider where the mapping from fluoropolymer application to downstream activity is less precise. For example, rail, maritime and some sealing applications use broad downstream denominators and therefore require wider low-to-high ranges. By contrast, the assumptions are narrower where manufacturer evidence points to well-defined applications or where product-level data provide a closer denominator. The central case should therefore be interpreted as a reasonable point estimate within an uncertainty range

2.2.4 Assumptions and limitations

The analysis is subject to the following caveats that should be kept in mind when interpreting the results.

- Fluoropolymers are not separately identified within official statistical classifications. The economic footprint modelling therefore uses CPA_C20, manufacture of chemicals and chemical products, as the closest available input-output proxy.
- Activity-share and criticality assumptions are necessarily judgement-based. They are informed by manufacturer evidence, ECHA application mapping and public economic data, but there is no official statistical source that directly identifies the share of downstream output dependent on fluoropolymer applications. The wide ranges for some effective dependency assumptions reflects the uncertainty inherent in mapping specialised fluoropolymer applications to broad downstream economic sectors.
- PRODCOM and SBS data are not identical measures. SBS reports sector-level output, GVA and employment, while PRODCOM reports product-level production values. Where PRODCOM is used, GVA and employment are estimated using ratios from the closest available SBS sector.
- Input-output models assume fixed production relationships between sectors and do not capture dynamic behavioural responses, substitution effects, technological adjustment or long-term market adaptation.

3 Economic footprint of EU fluoropolymer manufacturing

This chapter first considers the size and supply structure of the European fluoropolymer market, before estimating the economic footprint of fluoropolymer manufacturing within the EU. Total market demand captures the volume of fluoropolymers used by European downstream sectors, regardless of origin. The economic footprint estimates capture the direct, indirect and induced economic activity supported by fluoropolymer production within the EU. This chapter provides the basis for assessing the sector's contribution to the EU industrial base.

3.1 Size and supply structure of Europe's fluoropolymer market

Before estimating the economic footprint of EU fluoropolymer manufacturing, it is useful to distinguish between two related but different measures: the total size of the European fluoropolymer market and the economic activity supported by fluoropolymer manufacturing within the EU. The producer dataset provides the basis for estimating the latter. It captures production, sales and employment associated with responding EU manufacturers. These production data cover EU-produced fluoropolymers supplied both to the EU market and to export markets. They do not provide a complete estimate of the volume of fluoropolymers placed on the EU27 market, because the market is also supplied by imports from non-EU producers, including production from European countries outside the EU27.

To estimate the imports of fluoropolymers to the EU, we have analysed Comtrade data for the two main HS codes covering fluoropolymers in primary forms: HS 390461, covering polytetrafluoroethylene in primary forms, and HS 390469, covering other fluoropolymers in primary forms. Comtrade reports EU imports under these two codes of approximately 41.7 kt in 2025, comprising 23.3 kt under HS 390461 and 18.4 kt under HS 390469. This is substantially above the 9.7 kt of imports reported in the producer dataset and is broadly consistent with the conclusion that the producer data do not capture total import supply to the EU market.

Combining estimated EU27-produced supply sold into the EU27 with Comtrade import data implies a total EU27 market size in 2025 of approximately 56.5 kt. EU27-produced supply sold into the EU27 is calculated as EU27 production less exports outside the EU27.

A separate estimate of the market size can be developed through an extrapolation of the volumes set out in the previous socioeconomic analysis (SEA) of the European fluoropolymer industry by Wood, which estimated the market size in 2020 to be 40kt and cited research indicating expected compound annual growth for fluoropolymers of 6.5 per cent per annum.² Extrapolation of the 2020 estimate using the 6.5 per cent CAGR gives a 2025 estimate of 55kt. The 2023 FPG SEA provides a further cross-check.³ It reported that an update of the Wood analysis using member data estimated 2022 fluoropolymer volumes at 40–95 kt.

3.1.1 Estimated 2025 market size

The central estimate used in this report for the 2025 European fluoropolymers market is 56.5kt. This estimate is based on combining producer data with Comtrade statistics, cross-checked against the previous estimates

² Wood (2022) "Update of market data for the socioeconomic analysis (SEA) of the European fluoropolymer industry" [\[online\]](#)

³ Fluoropolymer Product Group (2023) "Socioeconomic impact assessment for fluoropolymers" [\[online\]](#)

of the market's size. The estimate should be interpreted as an indicative market-sizing assumption rather than a directly observed EU27 total.

Table 3.1 presents an indicative supply structure for the EU27 fluoropolymer market in 2025, based on the central market estimate. The producer data indicate that responding manufacturers produced approximately 29,500 tonnes of fluoropolymers in the EU27 in 2025 and exported approximately 15,000 tonnes outside the EU27. This implies that around 14,500 tonnes of EU27-produced fluoropolymers were supplied to the EU27 market.

Table 3.1: Estimated EU27 fluoropolymer market size and structure, 2025

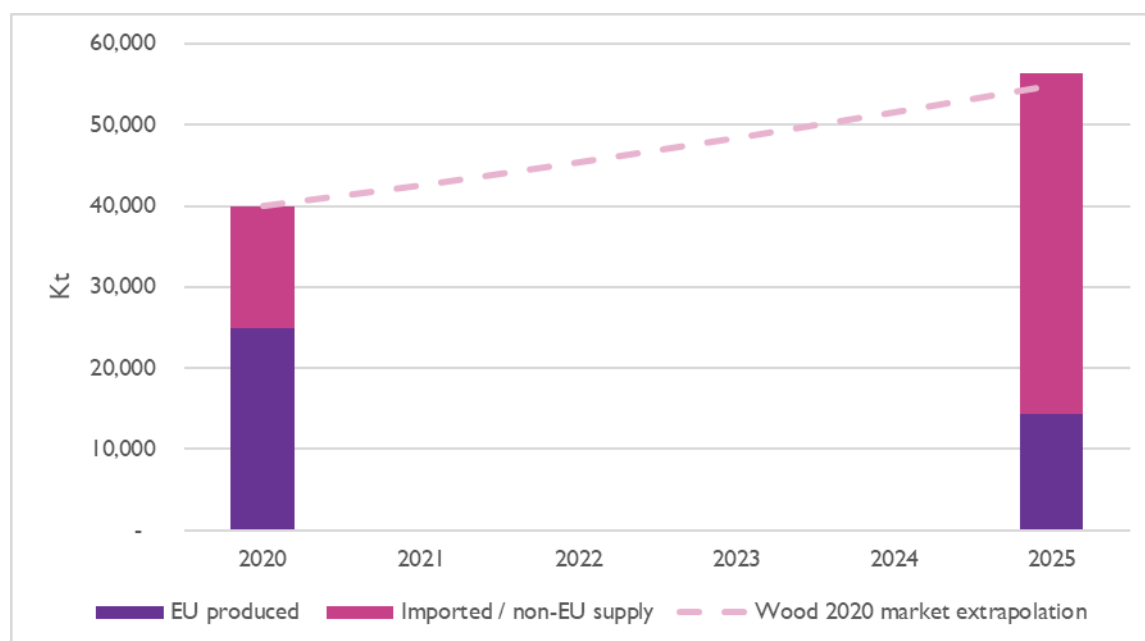
Quantities (tonnes)	EU27
Tonnes produced in the EU27	29,500
Tonnes imported into the EU27	42,000
Tonnes exported from the EU27	15,000
EU27-produced supply sold in the EU27	14,500
Tonnes sold in the EU27	56,500
Implied share of EU sales supplied by EU	25%
Implied share of EU sales supplied by non-EU	75%

Figures are rounded to the nearest 500 tonnes. Shares are calculated using unrounded figures where available and rounded to the nearest whole percentage point. Comtrade imports refer to EU imports reported under HS 390461 and HS 390469 in 2025. HS 390461 covers polytetrafluoroethylene in primary forms, while HS 390469 covers other fluoropolymers in primary forms.

On this basis, EU27-produced fluoropolymers are estimated to account for approximately 25 per cent of EU27 market sales in 2025, with non-EU supply accounting for the remaining 75 per cent. This indicates substantial reliance on supply from outside the EU27 production base.

Figure 3.1 compares Wood's 2020 estimate of fluoropolymers sold in the EU28 with the 2025 market estimate based on producer data and imports estimated from Comtrade. The 2025 estimate is closely aligned, although slightly above, the extrapolated Wood estimate. The analysis implies that the share of market demand supplied by imports or non-EU production has increased substantially, from around 38 per cent in 2020 to around 75 per cent in 2025.

This import dependence comparison should be interpreted cautiously because the 2020 and 2025 figures differ in geographic scope – UK production that would previously have been treated as part of the EU28/EEA production base is now treated as non-EU supply from an EU27 perspective. Nonetheless, the estimates indicate that the share on the EU market supplied from outside the EU27 production base has increased substantially.

Figure 3.1: Indicative change in European fluoropolymer market supply structure, 2020–2025

2020 figures are based on Wood's estimate of fluoropolymers sold in the EU28/EEA, split between EU-produced supply and imports. The 2025 figures are based on the central market estimate used in this report and producer data collected for this study. The dotted line shows an extrapolation of Wood's 2020 market estimate using the annual growth assumption referenced in the Wood analysis; it is included as an indicative trend rather than an observed market series.

3.2 Direct manufacturing footprint

Fluoropolymers are used in a range of industrial applications connected to wider European value chains, including advanced manufacturing and technology-intensive sectors. Their manufacture within the EU is therefore relevant as an economic activity in its own right and as an input into downstream industrial activity. This section quantifies the direct footprint of EU fluoropolymer manufacturing by assessing production, value, employment and trade position. These estimates provide the basis for understanding the sector's economic footprint and its links to wider industrial value chains.

3.2.1 Scale of EU production

In Table 3.2 we set out the core indicators of EU fluoropolymer manufacturing activity. In 2025, participating manufacturers produced around 29,500 tonnes of fluoropolymers in the EU, with a reported sales value of EU-produced product of approximately €620 million and direct employment of around 2,800 FTEs. This provides the baseline for assessing both the direct manufacturing footprint and the wider activity supported through upstream and downstream value chains.

Table 3.2: EU Fluoropolymer Manufacturing Footprint: Production, Value and Employment (2025)

Category	Value
Tonnes produced in EU (t)	29,500
Reported sales value of product produced in the EU (€m)	620
Direct employment (FTE)	2,800

Sales values are reported in € million and rounded to two significant figures. Production volumes are rounded to the nearest 100 tonnes. Employment is reported in full-time equivalents (FTE) and rounded to the nearest 100. The reported sales value of product produced in the EU is based on manufacturer responses and is used as the direct output measure for the economic footprint modelling.

3.2.2 Exports

EU fluoropolymer manufacturers supply substantial volumes to non-EU markets. Table 3.3 presents exports of EU-produced fluoropolymers by the responding manufacturers to non-EU markets in 2025. Participating manufacturers exported around 15,200 tonnes of EU-produced fluoropolymers, with a sales value of approximately €700 million. This indicates that EU production contributes both to EU market supply and to international value chains, as well as supporting the EU's external trade position in specialised materials.

Table 3.3: EU Fluoropolymer Exports to Non-EU Markets (2025)

Export metric	Value
Tonnes exported from EU production to outside the EU (t)	15,200
Sales value of exports from EU production (€m)	700

Sales values are reported in € million and rounded to two significant figures. Export volumes are rounded to the nearest 100 tonnes.

3.3 Wider economic footprint

The wider economic footprint captures the total activity supported by fluoropolymer manufacturing across the European economy. This includes the direct activity of EU fluoropolymer producers, indirect effects through purchases from upstream suppliers, and induced effects associated with household spending by workers and shareholders supported directly and indirectly by the sector.

In Table 3.5 we summarise the direct, indirect, induced and total effects in 2025. These estimates are based on multipliers derived from input-output tables for the EU economy. Fluoropolymer manufacturing is not separately identified in the input-output framework, so the analysis uses the closest available sector proxy, chemicals and chemical products. Direct fluoropolymer output is applied to this sector, and the input-output relationships are used to estimate the additional activity supported across suppliers and the wider economy.

Two sets of multipliers are used. Type I multipliers capture direct and indirect effects, including the activity supported through purchases from upstream suppliers. Type II multipliers include these effects and also capture induced activity generated when wages supported by direct and indirect activity are spent in the wider economy. On this basis, the Type II output multiplier is 2.61, meaning that each €1 of direct fluoropolymer output supports approximately €2.61 of output across the EU economy once direct, indirect and induced effects are included.

Table 3.4: Parameters and multipliers used in economic modelling

Multiplier / coefficient	Value	Interpretation
GVA coefficient	0.24	Direct GVA generated per €1 of direct fluoropolymer output.
Type I output multiplier	2.18	Direct and indirect output supported per €1 of direct fluoropolymer output.
Type II output multiplier	2.61	Direct, indirect and induced output supported per €1 of direct fluoropolymer output.
Type I GVA multiplier	0.69	Direct and indirect GVA supported per €1 of direct fluoropolymer output.
Type II GVA multiplier	0.89	Direct, indirect and induced GVA supported per €1 of direct fluoropolymer output.
Type I employment multiplier	7.28	Direct and indirect FTE jobs supported per €1 million of direct fluoropolymer output.
Type II employment multiplier	23.5	Direct, indirect and induced FTE jobs supported per €1 million of direct fluoropolymer output.

The equivalent Type II GVA multiplier is 0.89, meaning that each €1 of direct fluoropolymer output supports approximately €0.89 of GVA across the economy. The employment multiplier is 23.5 FTE jobs per €1 million

of direct output, reflecting the direct jobs supported in fluoropolymer manufacturing and the additional jobs supported through supply-chain and wage-spending effects.

Applying these multipliers to the direct manufacturing footprint, the model estimates that EU fluoropolymer manufacturing supports approximately €1.6 billion of output, €550 million of GVA and 14,500 FTE jobs across the EU economy. This is substantially larger than the direct footprint alone, which is approximately €620 million of output, €150 million of GVA and 2,800 FTE jobs.⁴ The difference reflects the sector's links to upstream industries – including chemicals, utilities, wholesale trade, refined petroleum products, transport and professional services – and the wider economic activity supported through household spending.

Table 3.5: Wider Economic Footprint of EU Fluoropolymer Manufacturing (2025)

Effects	Output (€m)	GVA (€m)	Employment (FTE)
Direct	620	150	2,800
Indirect	730	280	1,700
Induced	260	120	10,000
Total	1,600	550	14,500

Monetary values are reported in € million and rounded (for Direct, Indirect and Induced lines, though not for Totals) to two significant figures. Employment is reported in full-time equivalents (FTE) and rounded to the nearest 100. Multipliers are derived from EU input-output tables.

The Type II employment effect is larger than the direct and indirect employment effects because it includes employment supported through household spending by workers whose jobs are supported directly or indirectly by EU fluoropolymer manufacturing. This induced effect is spread across a wide range of consumer-facing and service sectors, which are generally more labour-intensive than fluoropolymer manufacturing itself. The Type II employment estimate should therefore be interpreted as the wider economy-wide employment supported by the sector, rather than employment within fluoropolymer manufacturing or its immediate supply chain alone.

3.4 Upstream supply-chain

Fluoropolymer manufacturing generates demand for intermediate inputs from a range of upstream sectors. These supply-chain effects show how production in the sector translates into output in other parts of the European economy, reflecting its integration within the wider industrial base.

Table 3.6 identifies the upstream sectors most affected through the supply chain, ranked by output impact. The largest indirect effect is in chemicals and chemical products, at approximately €130 million, representing 19 per cent of total indirect output. This reflects the sector's reliance on chemical inputs and related intra-sector supply-chain activity. Other material upstream impacts are observed in wholesale trade, utilities, refined petroleum products, professional services and land transport. Together, the six sectors shown in Table 3.6 account for almost half of total indirect output. This concentration reflects the combination of specialist chemical inputs, energy use, logistics and business services required to support fluoropolymer manufacturing.

⁴ To see the relationship between these figures and the multipliers set out above, it may help to note that, for example, $0.89 \times €0.62\text{bn} = €0.55\text{bn}$, whilst $€0.62\text{bn} \times 2.61 = €1.6\text{bn}$ and $23.5 \times 620 = 14,570$ (difference due to rounding).

Table 3.6: Top Upstream Sectors by Output Impact from EU Fluoropolymer Manufacturing (2025)

CPA category	Sector	Output Impact (€m)	Share of Total Indirect Output (%)
CPA_C20	Chemicals and chemical products	130	19
CPA_G46	Wholesale trade, except motor vehicles	58	8
CPA_D	Electricity, gas, steam and air conditioning	51	7
CPA_C19	Coke and refined petroleum products	42	6
CPA_M69_70	Legal, accounting, management and consultancy activities	37	5
CPA_H49	Land transport and transport via pipelines	29	4

CPA_C20 (chemicals and chemical products) excludes direct fluoropolymer manufacturing activity and reflects only additional intra-sector supply-chain effects within the chemicals sector. Monetary values are reported in € million and rounded to two significant figures. Shares are calculated using unrounded values and rounded to the nearest whole percentage point.

3.5 What these results show

The results in this chapter show that EU fluoropolymer manufacturing has an economic footprint that extends beyond the direct value of production. In 2025, the responding manufacturers directly supported approximately **€620 million of output**, **€150 million of GVA** and **2,800 FTE jobs**. Once indirect and induced effects are included, the estimated economy-wide footprint rises to approximately **€1.6 billion of output**, **€550 million of GVA** and **14,500 FTE jobs**.

The analysis also shows that EU fluoropolymer manufacturing is embedded in wider industrial supply chains. The sector supports upstream activity in chemicals, utilities, refined petroleum products, logistics, wholesale trade and professional services. These linkages mean that disruption to EU fluoropolymer manufacturing would not only affect the producers themselves, but would also have implications for suppliers and related economic activity across the EU economy.

The supply data further indicate that EU production remains an important source of fluoropolymers placed on the EU market within the responding manufacturer dataset, while EU producers also supply non-EU markets. This points to the role of EU fluoropolymer manufacturing both as a domestic supply base and as part of international value chains.

The key implication is that the economic significance of fluoropolymers cannot be assessed only by reference to the direct value of production. EU fluoropolymer manufacturing supports upstream activity across the economy and supplies downstream applications in strategic sectors. The next chapter therefore examines the scale of downstream value potentially exposed where fluoropolymers perform enabling functions and substitution options are limited. The downstream analysis considers a different but complementary question: the scale of economic activity in sectors that depend on continued access to fluoropolymers for specific applications where substitution may be difficult or not technically viable.

4 Downstream value at risk

Fluoropolymers are enabling inputs in a wide range of downstream applications, including defence, transport, medical technologies, energy technologies, semiconductors, electronics, sealing systems and wider industrial uses. In many of these applications, they account for a small share of final product value but provide functions that are difficult to replicate, including chemical resistance, thermal stability, durability, electrical performance and reliability in demanding operating environments.

This means that the economic relevance of fluoropolymers cannot be assessed by reference to fluoropolymer sales alone. Where substitution is difficult or not viable in the short run, reduced access to fluoropolymers could expose substantially larger downstream value chains. This chapter therefore estimates the downstream output, GVA and employment associated with selected fluoropolymer-dependent applications under a baseline no-derogation scenario. The analysis focuses on transport, energy and sealings, reflecting their economic materiality, technical criticality and relevance to EU industrial capability.

4.1 Mapping fluoropolymers to downstream uses

The analysis begins by mapping fluoropolymer sales to ECHA application sectors to provide an indication of where demand for these materials is concentrated and how fluoropolymer supply is connected to downstream manufacturing activity.

The ECHA mapping provides a common structure for classifying fluoropolymer uses, but it should not be interpreted as a set of mutually exclusive downstream economic sectors in all cases. Some categories describe end-use sectors, such as transport or energy, while others describe application types that can occur across several sectors. Sealing applications are the clearest example: fluoropolymer seals, gaskets, O-rings and related components may be used in transport, energy, semiconductor manufacturing, chemical processing and wider industrial equipment.

Pharmaceutical-related uses are not quantified as a separate downstream sector in this analysis. However, they are relevant to several categories covered by the mapping, including medical applications, other medical uses, broader industrial uses and cross-cutting applications such as high-performance sealings. These uses may be important to pharmaceutical and biopharmaceutical manufacturing, where fluoropolymers may support high-purity fluid handling, filtration, process equipment, gaskets and seals used in demanding chemical, sterile or regulated operating environments.

The figures in Table 4.1 are based on manufacturers' best efforts to classify sales according to the ECHA application categories. As a result, they provide a useful indication of where fluoropolymers are used, but some categories should be interpreted as application mappings rather than final downstream sectors. This is reflected in the value-at-risk analysis, which treats sealings as a cross-cutting application category and avoids adding sealing-related exposure mechanically to sector estimates where this could create double-counting.

These figures measure the value and volume of fluoropolymers sold into each application area. They do not measure the full downstream economic activity supported by those applications. The value-at-risk analysis therefore uses these sales data as a mapping tool, alongside public economic data, to estimate the larger downstream output, GVA and employment potentially exposed.

Table 4.1: EU Fluoropolymer Sales to Downstream Applications by ECHA Sector (2025)

ECHA Sector	Sum of Value sold onto EU market (€m)	Sum of Quantity sold onto EU market (t)
Sealing applications	330	10,000
Transport	130	5,100
Lubricants	84	900
Electronics and semiconductors (Semiconductors)	64	2,200
Broader industrial uses	60	2,200
Energy	50	1,200
Electronics and semiconductors (Electronics)	30	700
Technical Textiles	20	900
Construction products	18	1,100
Food contact materials (FCM) and packaging	13	900
Medical devices	12	300
Other medical applications	4	100
Military applications	2	100

Monetary values are reported in € million and rounded to approximately two significant figures, with additional rounding applied to smaller values for confidentiality reasons. Production volumes are rounded to the nearest 100 tonnes.

The results show that demand is not concentrated in a single end market. Sealing applications account for the largest reported EU market sales, at around €330 million and 10,000 tonnes, followed by transport at around €130 million and 5,100 tonnes. Electronics and semiconductors, broader industrial uses and energy applications also account for material sales. However, the ranking of direct fluoropolymer sales should not be read as a ranking of downstream value-at-risk. Downstream exposure depends not only on the value of fluoropolymer inputs, but also on the scale of the downstream value chain and the extent to which fluoropolymers are technically substitutable.

For the value-at-risk analysis, we asked manufacturers to provide more detailed mapping for three priority areas: transport, energy and sealings. The additional mapping was used to identify more precisely which downstream activities were linked to fluoropolymer applications in these areas.

This additional step was particularly important for sealings. In the ECHA mapping, sealing applications are reported as a distinct category, but sealings are not a single downstream sector. Fluoropolymer seals, gaskets, O-rings and related components can be used across transport, energy, semiconductor manufacturing, chemical processing and wider industrial applications. Table 4.2 therefore shows how sealing applications have been allocated to downstream uses where manufacturers provided sufficient information. For this reason, the values used in the downstream value-at-risk analysis do not necessarily correspond one-for-one to the rows in the ECHA mapping in Table 4.1.

Table 4.2: Mapping of sealings applications to downstream sectors (2025)

Downstream sector	Tonnes (t)	Value (€m)	Criticality
Transport	4,400	157	High
Energy and other strategic uses	2,700	110	Medium to High (depending on application)
Semiconductors	1,100	56	High

Monetary values are reported in € million and rounded to two significant figures. Production volumes are rounded to the nearest the nearest 100 tonnes. Energy has been aggregated with other strategic uses for confidentiality reasons, where category-level reporting did not meet the minimum disclosure threshold.

Transport applications account for around **4,400 tonnes** and **€157 million** of reported sales of sealings, while semiconductor applications account for around **1,100 tonnes** and **€56 million**. Energy and other strategic uses are smaller in reported sealings sales, but include applications such as photovoltaic and hydrogen technologies.

4.2 Economic scale of downstream fluoropolymer-using sectors

Fluoropolymers are used in downstream sectors that are substantially larger than the fluoropolymer market itself. This is because fluoropolymers often account for a small share of input value but perform enabling functions in products or processes where performance, durability, chemical resistance, electrical insulation or reliability are important. Table 4.3 summarises the economic scale of selected downstream sectors and product markets in which fluoropolymers are used. The table is intended to provide context for the value-at-risk analysis. It does not imply that the full output of each sector is dependent on fluoropolymers.

Table 4.3: Economic scale of selected downstream sectors in which fluoropolymers are used

Sector	Output (€ m)	Source and scope note
Automotive	1,068,214	Eurostat SBS/CPA, 2023. Based on CPA/NACE C29 motor vehicles, trailers and semi-trailers. This is a broad sector-level proxy for fluoropolymer-relevant automotive activity, not a targeted estimate of fluoropolymer-using applications.
E-mobility	121,200	Eurostat PRODCOM, 2024. Based on selected electric and hybrid passenger vehicle categories. This provides a targeted estimate of e-mobility manufacturing output linked to fluoropolymer use but excludes imports.
Semiconductors	17,532	Eurostat PRODCOM, 2023. Based on a central semiconductor product set; targeted semiconductor manufacturing estimate.
Construction	2,472,612	Eurostat NACE, 2024. Based on NACE F41–43 construction sector data. This represents the total reported size of the construction sector, used as a broad context proxy for fluoropolymer-relevant activity. Fluoropolymers are used in selected construction applications such as roof/façade coatings, bearings, greenhouse films and PTFE thread sealings, but the estimate is not limited to those applications.
Renewable energy	13,872	Eurostat PRODCOM, 2024. Based on selected renewable-energy equipment categories. This provides a targeted but not exhaustive estimate of renewable-energy manufacturing output linked to fluoropolymer use but excludes imports.
Advanced medical applications	12,339	Eurostat PRODCOM, 2024. Based on selected advanced medical manufacturing categories. This provides a targeted estimate of medical manufacturing output linked to fluoropolymer use, although some included diagnostic equipment categories are broader.

Output values are reported in € million and rounded to the nearest € million. Estimates use the most relevant available Eurostat source for each sector. PRODCOM figures capture sold production for selected product categories and are therefore narrower, product-specific estimates that

exclude imports. CPA/NACE figures capture turnover or sector-level activity for broader sectors or categories; these are wider in scope and may include sales of imported goods where relevant but are not targeted estimates of fluoropolymer-using activity.

The table illustrates the scale difference between fluoropolymer supply and the downstream sectors in which fluoropolymers are used. These differences are reflected in the value-at-risk analysis through the activity-share and criticality assumptions applied to the relevant downstream denominators.

4.3 Results under the baseline no-derogation scenario

The results below estimate downstream economic activity exposed under the baseline no-derogation scenario. They should be interpreted as measures of value at risk, rather than forecasts of losses. The results are presented for transport, energy and sealing applications. As set out above, sealing applications are cross-cutting and should therefore be interpreted alongside, rather than added mechanically to, the sector estimates.

The value-at-risk analysis is based on downstream economic denominators – such as transport manufacturing, energy technologies and semiconductor-related production – and on assumptions about the share of those activities that depend on fluoropolymer applications, developed from the responses from manufacturers. The downstream value at risk does not depend directly on whether the fluoropolymer inputs used by downstream firms are produced in the EU27 or imported. The baseline scenario concerns restricted access to fluoropolymer applications in the EU market, rather than the origin of the fluoropolymer supply. What matters for the exposure calculation is the scale of the downstream activity and the extent to which that activity is dependent on fluoropolymers in the short run.

This means that the market-sizing evidence in Section 3.1 provides important context for interpreting the results, rather than a separate basis for estimating downstream exposure. The market-sizing analysis indicates that EU downstream users rely on a combination of EU-produced and imported fluoropolymer supply. The results in this section therefore capture the scale of downstream EU activity potentially exposed where continued access to fluoropolymers is constrained, regardless of whether the current supply is domestic or imported.

4.3.1 Transport

Transport represents the largest quantified downstream exposure. Fluoropolymers are used in applications linked to road vehicles, aerospace, rail and maritime equipment, including components operating under demanding thermal, chemical, mechanical or safety-critical conditions. Manufacturer evidence indicates high criticality across several transport applications, reflecting limited short-run substitution options and the need for performance, durability and regulatory compliance in final products.

The transport estimate is based on SBS data for relevant transport manufacturing sectors. Activity-share assumptions are used to identify the portion of sector output exposed to fluoropolymer-dependent applications, while criticality assumptions reflect the manufacturer evidence on substitutability.

Table 4.4: Total transport value at risk under baseline no-derogation scenario

Impact Metric	Low	Central	High
Output at risk (€m)	190,000	330,000	520,000
GVA at risk (€m)	43,000	77,000	120,000
Employment at risk (FTE)	405,400	727,100	1,129,500

Monetary values are reported in € million and rounded to two significant figures. Employment is reported in full-time equivalents (FTE) and rounded to the nearest 100.

In the central case, approximately **€330 billion of transport output, €77 billion of GVA and 727,100 FTE jobs** are exposed. The largest exposure is in road vehicles, with additional exposure in aerospace, rail and maritime applications.

4.3.2 Energy

Energy-related applications include PV products, hydrogen technologies, lithium-ion batteries for non-EV uses, and chlor-alkali membranes. These applications are relevant to clean technology value chains, industrial decarbonisation and energy-system resilience.

The modelling uses product-level PRODCOM data for PV and lithium-ion batteries, where product-level data provide a better denominator than broad or confidential SBS business sectors. For hydrogen technologies and chlor-alkali membranes, SBS sectors are used with activity-share assumptions to isolate the relevant downstream activity. Criticality varies by application. PV applications are generally assessed as difficult to substitute, while hydrogen technologies, batteries and chlor-alkali membranes are generally assessed as highly critical based on manufacturer evidence.

Table 4.5: Total Energy Value at Risk under Baseline No-Derogation Scenario

Impact Metric	Low	Central	High
Output at risk (€m)	3,700	9,000	16,000
GVA at risk (€m)	1,200	2,900	5,000
Employment at risk (FTE)	9,900	25,000	43,700

Monetary values are reported in € million and rounded to two significant figures. Employment is reported in full-time equivalents (FTE) and rounded to the nearest 100.

In the central case, energy-related applications account for approximately **€9.0 billion of output, €2.9 billion of GVA and 25,000 FTE jobs** exposed. While this is smaller than the transport exposure, the affected applications are strategically important because they are linked to clean technology, hydrogen production, battery storage and core industrial chemical processes.

4.3.3 Sealings

Sealings are treated as a cross-cutting application group rather than a single downstream sector. Fluoropolymer sealings are used in transport, energy, semiconductor and wider industrial applications, often where chemical resistance, reliability and durability are required under demanding conditions. These results should be interpreted carefully because sealing applications overlap with the transport and energy estimates.

Semiconductor sealings are modelled using PRODCOM semiconductor product values, excluding PV products to avoid double-counting with the energy analysis. Transport and energy sealings are modelled using the same underlying downstream data as for each of those sectors in the previous two sub-sections.

Table 4.6: Total Sealings Value at Risk under Baseline No-Derogation Scenario

Impact Metric	Low	Central	High
Output at risk (€m)	8,000	20,000	36,000
GVA at risk (€m)	2,000	5,100	8,800
Employment at risk (FTE)	23,000	54,900	94,800

Monetary values are reported in € million and rounded to two significant figures. Employment is reported in full-time equivalents (FTE) and rounded to the nearest 100.

In the central case, sealing applications are associated with approximately **€20 billion of output, €5.1 billion of GVA** and **54,900 FTE jobs** exposed. These results illustrate the potential scale of downstream activity linked to high-performance sealing applications, particularly where manufacturer evidence indicates that substitution is difficult or not technically viable in the short run.

4.4 Strategic sectors, transversal applications and production viability

The value-at-risk results are relevant to the EU's wider objectives on competitiveness, economic security and strategic autonomy. The results indicate that fluoropolymers are not only inputs into fluoropolymer manufacturing supply chains, but also enabling materials for downstream sectors that are strategically important to the EU. This is consistent with the EU's current policy focus on strengthening industrial resilience, supporting the clean transition, reducing strategic dependencies and maintaining capability in advanced technologies.

The policy relevance of the results differs by application. In transport, the exposure relates to one of the EU's largest industrial ecosystems, including road vehicle, aerospace, rail and maritime manufacturing. The European Commission has identified the car industry as a vital part of the EU economy, providing 13 million jobs and contributing 7 per cent of EU GDP,⁵ and its Automotive Action Plan places emphasis on competitiveness, clean mobility and supply-chain resilience.⁶ The transport results therefore matter not only because they are large in quantitative terms, but because disruption to key enabling inputs could affect value chains that the EU is actively seeking to keep competitive during the transition to low- and zero-emission mobility.

In energy, the quantified exposure is smaller than in transport, but the strategic significance is high. The affected applications include photovoltaic products, hydrogen technologies, non-EV lithium-ion batteries and chlor-alkali membranes. These are linked directly to clean technology deployment, energy-system resilience and industrial decarbonisation. This aligns with the Net-Zero Industry Act,⁷ which aims for EU manufacturing capacity for strategic net-zero technologies to approach or reach at least 40 per cent of annual deployment needs by 2030, and which identifies technologies including solar photovoltaic, electrolyzers and fuel cells, and batteries and storage. It also aligns with the Clean Industrial Deal, which frames clean-tech manufacturing and industrial decarbonisation as central to EU competitiveness.⁸

Sealing applications add a further strategic dimension because they are embedded across multiple downstream sectors. High-performance fluoropolymer seals, gaskets, O-rings and related components are used in applications where reliability, chemical resistance and durability are required under demanding operating conditions. The semiconductor-related sealing results are particularly relevant because they relate

⁵ European Commission (2025) "Boosting the European car sector" [\[online\]](#)

⁶ European Commission (2025) "Commission boosts European automotive industry's global competitiveness" [\[online\]](#)

⁷ European Commission "Net-Zero Industry Act" [\[online\]](#)

⁸ European Commission "Clean Industrial Deal" [\[online\]](#)

to a sector in which the EU has explicit objectives to strengthen its technological leadership and reduce reliance on third countries. The European Chips Act is intended to build up the EU semiconductor ecosystem, including design, manufacturing and packaging of advanced chips, and to support the Digital Decade target of doubling the EU's global market share in semiconductors to 20 per cent.⁹

These links to EU policy objectives do not mean that all downstream activity identified in the value-at-risk analysis would be lost under the proposed restrictions. The estimates should remain understood as measures of exposure. However, they show that the potential effects of restricting fluoropolymer applications would not be limited to the direct fluoropolymer market. Where fluoropolymers perform technically enabling functions, restrictions could create bottlenecks in downstream value chains, increase uncertainty for manufacturers, or shift reliance towards non-EU sources of materials, components or finished products.

This is relevant to the proportionality assessment. The EU's Economic Security Strategy identifies risks to supply-chain resilience, critical infrastructure, technology security and the weaponisation of economic dependencies as priority areas.¹⁰ The Competitiveness Compass similarly identifies decarbonisation and reducing dependencies as central requirements for restoring EU competitiveness.¹¹ In this context, the key issue is not simply whether fluoropolymer sales are large or small in absolute terms, but whether access to fluoropolymer applications supports downstream capabilities that the EU considers strategically important. Indeed, derogations for individual selected strategic uses — for example defence, aerospace or other critical applications — may not alone be sufficient to preserve the EU fluoropolymer supply base. Some strategic uses of transversal fluoropolymer applications, such as sealings and lubricants, may account for relatively small volumes which alone may not be enough for production to be economically viable (i.e. there's a minimum production volume below which manufacturing fluoropolymers is not viable). If restrictions remove a substantial share of the wider demand base EU production could become less viable even where narrowly selected strategic uses are formally derogated. The consequence could be that critical downstream sectors in the EU become increasingly dependent on non-EU supply of finished / semi-finished goods containing fluoropolymers, despite the EU's intention in providing a derogation.

Overall, the results suggest that the proposed restriction should be assessed in light of both direct and downstream effects. In sectors such as transport, clean energy technologies and semiconductors, the relevant risk is that a restriction on a relatively small but technically enabling input could have wider implications for value chains that support EU competitiveness, decarbonisation and resilience.

4.5 Implications of a derogation-based approach

The baseline no-derogation results show the scale of downstream activity exposed if fluoropolymer applications are restricted and no derogations apply. In practice, the proposed restriction includes derogations or alternative controlled-use approaches for some applications. The relevant question is therefore whether those derogations are sufficient to preserve the economic and strategic benefits identified in the previous chapters.

We use manufacturer input, supplemented by review of the proposed derogation framework, to inform assumptions for the share of relevant fluoropolymer sales value that remains restricted.¹² The derogation-adjusted value at risk is calculated by applying the relevant residual restricted share to the baseline no-derogation output, GVA and employment estimates.

The assumptions are that 50 per cent of relevant transport fluoropolymer sales value remains restricted, 90 per cent of relevant energy sales value remains restricted, and 100 per cent of relevant sealing sales value

⁹ European Commission “The EU budget bolsters Europe’s technological leadership: the European Chips Act” [[online](#)]

¹⁰ European Commission “An EU approach to enhance economic security” [[online](#)]

¹¹ European Commission, Competitiveness Compass [[online](#)]

¹² European Chemicals Agency (ECHA) “SEAC Draft Opinion on PFAS restriction proposal” [[online](#)]

remains restricted. These assumptions reflect the relatively narrow or uncertain coverage of the derogation framework, particularly for cross-cutting and energy-related fluoropolymer applications.

Table 4.7: Derogation-adjusted downstream value at risk

Area	Central baseline output at risk	Residual restricted share	Derogation-adjusted output at risk	Derogation-adjusted GVA at risk	Derogation-adjusted employment at risk
Transport	€330bn	50%	€165bn	€39bn	364,000 FTE
Energy	€9.0bn	90%	€8.1bn	€2.6bn	22,500 FTE
Sealings	€20bn	100%	€20bn	€5.1bn	54,900 FTE

The results are based on central baseline value-at-risk estimates. Sealings are a cross-cutting application category and should be interpreted alongside, rather than added mechanically to, the transport and energy estimates. Monetary values and employment are rounded.

The results should be interpreted as a **short-term derogation coverage assessment**. They do not account for the expiry of time-limited derogations, uncertainty over the final legal scope of the restriction, or the operational feasibility of supplying only derogated uses. As a result, even where the short-term residual restricted share is materially reduced, derogations may still be too fragmented, uncertain or administratively complex to preserve the economic and strategic benefits identified in the preceding chapters.

Applying these residual restricted shares to the central baseline value-at-risk estimates gives an indication of the scale of value that could remain exposed even after derogations are taken into account. For transport, the derogation case implies that around **€165 billion of output, €39 billion of GVA and 364,000 FTE jobs** could remain at risk. For energy, the equivalent estimates are approximately **€8.1 billion of output, €2.6 billion of GVA and 22,500 FTE jobs**, while for sealings the figures are the same as the baseline scenario.

Overall, the derogation adjustment indicates that material downstream value could remain at risk under a derogation-based approach.

4.6 What these results show

The downstream analysis shows that the economic significance of fluoropolymers extends beyond the direct value of fluoropolymer sales. In the central baseline no-derogation scenario, fluoropolymer applications are associated with approximately €330 billion of transport output, €9 billion of energy-related output and €20 billion of sealing-related output exposed. The corresponding GVA exposures are approximately €77 billion, €2.9 billion and €5.1 billion, respectively.

These estimates are best interpreted as measures of downstream exposure. They identify the scale of economic activity associated with applications where fluoropolymers perform enabling functions and where short-run substitution may be difficult or not viable. They are not forecasts that this activity would necessarily be lost in full. The results nevertheless show that the potential economic relevance of fluoropolymers cannot be inferred from fluoropolymer sales values alone.

The transport results account for the largest quantified exposure, reflecting the scale of EU transport manufacturing and the use of fluoropolymer applications in components subject to demanding performance, durability, safety and regulatory requirements. The energy results are smaller in aggregate, but are strategically important because they relate to clean technology deployment, hydrogen production, battery storage and industrial chemical processes. The sealing results should be interpreted separately and with care, because sealing applications are cross-cutting and overlap with some transport and energy uses. They nevertheless illustrate the importance of high-performance sealing applications, including in semiconductor-related uses where overlaps with the transport and energy estimates are more limited.

The overall implication is that fluoropolymers should be assessed as enabling inputs within wider industrial value chains. For the proportionality assessment, the relevant question is not only the direct footprint of fluoropolymer manufacturing, but also the downstream activity and strategic capabilities that may depend on continued access to fluoropolymer applications. This is particularly important where substitution options are limited in the short run and where affected applications support EU objectives on competitiveness, decarbonisation, advanced manufacturing and supply-chain resilience.



Case studies

Laboratory equipment is vital to making scientific advancements

Laboratory equipment is irreplaceable in the healthcare industry, in food and environmental monitoring and in the chemical industry as well. The equipment serves to develop pharmaceuticals, do research, and investigate diseases, among others.

PFAS in the form of fluoropolymers and fluoroelastomers are used in laboratory equipment as these materials are characterised by high resistance levels against chemicals and extreme purity. Currently there are no available alternatives providing the same combination of properties for laboratory use.

The PFAS are needed only in small quantities, when they are used in the parts of the equipment that come in contact with the chemicals. For instance, they are used in sampling and analysis equipment since they do not affect the parameters to be investigated and monitored, and do not interact with the chemicals or samples. Due to their exceptional purity, they are also used to prevent contamination when storing or transporting liquids.

Since this equipment is used specifically in a laboratory setting, it is handled by either professionals or supervised students within a secure environment. This means that, at the end of the life cycle, the decommissioned equipment is disposed through the industrial waste system and can be treated according to local and international law.



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An overview of the uses of per- and polyfluoroalkyl substances (PFAS)

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Abstract

Per- and polyfluoroalkyl substances (PFAS) are of concern because of their very high persistence and impacts on human and environmental health. Currently, many different PFAS (on the order of several thousands) are used in a wide range of applications and there is no comprehensive source of information on the many individual substances and their functions in different applications. Here we provide a broad overview of many use categories where PFAS have been employed and for which function; we also specify which PFAS have been used and discuss the magnitude of the uses. Our compilation is not exhaustive, but it was still possible to demonstrate that PFAS are used in almost all industry branches and many consumer products. In total, more than 200 use categories and subcategories were identified for more than 1400 individual PFAS. The identified use categories include many categories not previously described in the scientific literature but also a lot of well-known categories such as textile impregnation, fire-fighting foam, and electroplating. Besides a detailed description of use categories, the present study also contains a list of the identified PFAS per use category. On this basis, a database of exact masses of 1400 PFAS is provided that is intended to facilitate the analytical detection of many more individual PFAS in the future.

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3 Introduction

Per- and polyfluoroalkyl substances (PFAS) are a class of thousands of substances^{1,2} that have been produced since the 1940s and used in a broad range of consumer products and industrial applications.³ Based on concerns regarding the high persistence of PFAS⁴ and the lack of knowledge on properties, uses, and toxicological profiles of many PFAS currently in use, it has been argued that the production and use of PFAS should be limited.⁵ However, there are specific uses that make an immediate ban of all PFAS impractical. Some specific uses of PFAS may currently be essential to health, safety or the functioning of today's society for which alternatives so far do not exist. On the other hand, if some uses of PFAS are found to be non-essential, they could be eliminated without having to first find alternatives that provide an adequate function and performance. To determine which uses of PFAS are essential and which are not, the concept of "essential use," as defined under the Montreal Protocol, has recently been further developed for PFAS, including illustrative case studies for several major use categories of PFAS.⁶

PFAS are costly to produce (e.g. fluorosurfactants are 100–1000 times more expensive than conventional hydrocarbon surfactants per unit volume⁷) and therefore are often used where other substances cannot deliver the required performance,¹ or where PFAS can be used in a much smaller amount and with the same performance as a higher amount of a non-fluorinated chemical. Examples are uses that operate over wide temperature ranges or uses that require extremely stable and non-reactive substances. The C-F bonds in PFAS lead to very stable substances, a feature that also makes them very persistent in the environment. Furthermore, the perfluorocarbon moieties in PFAS are both hydrophobic and oleophobic, making many PFAS effective surfactants or surface protectors.⁸ PFAS-based fluorosurfactants can lower the surface tension of water to less than 16 mN/m, which is half of what is attainable using hydrocarbon surfactants.^{8,9} Likewise, the surfaces of fluorinated polymers have about half the surface tension compared to hydrocarbon surfaces. For instance, a close-packed, uniformly organized array of trifluoromethyl (-CF₃) groups creates a surface with a solid surface tension as low as 6 mN/m.¹⁰

Due to these and other desirable properties, PFAS are used in many different applications. A good overview of the range of uses of PFAS as surfactants and repellents is provided in the monograph by Kissa (2001).³ It lists 39 use categories, mostly derived from patents, and describes the function of PFAS in these use categories. However, the work by Kissa (2001) was published nearly 20 years ago, focused on fluorosurfactants and repellents, and it is not clear which of these uses are still relevant today. In addition to Kissa (2001),³ there are a few other monographs and a large number of peer-reviewed scientific articles and reports that contain information on uses of PFAS.^{8,11,20,12–19} While these articles and reports provide useful information, each of them focuses on the uses of a specific PFAS group (in specific use categories). This is also the case for the information from the Persistent Organic Pollutants Review Committee (POPRC) that is mainly related to perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), their precursors, and the PFAS that can be or have been substituted for these PFAS.^{21–27} The FluoroCouncil²⁸ has provided further information on uses of PFAS. However, the

information is rather generic and contains few details about specific uses and substances. Hence, a comprehensive overview that summarizes major current uses is missing.

The present paper, together with the Appendix and the Electronic Supplementary Information (ESI), attempts to provide a broad (but not exhaustive) overview of the uses of PFAS. It addresses the following points: i) In which use categories have PFAS been employed and for which functions? ii) Which PFAS have been and are used for a certain category? and iii) What is the magnitude of the uses, and can uses be ranked by quantity? Within the European Union (EU), there are discussions underway for a proposal to restrict PFAS uses to those that are essential and copious information on the uses will be needed to prepare such a restriction proposal.²⁹ The present work is intended to support this process by showing in which applications PFAS are used and which functionality they were selected for.

4 Methods

4.1 Which PFAS are addressed?

A first clear definition of PFAS was provided by Buck et al. (2011).¹ They defined PFAS as aliphatic substances with the moiety $-C_nF_{2n+1}$ where n is at least 1. The OECD/UNEP Global PFC Group noted that many substances, containing other perfluorocarbon moieties (e.g. $-C_nF_{2n}-$), were not commonly recognized as PFAS according to Buck et al. (2011), e.g. perfluorodicarboxylic acids.² Considering their structural similarities to commonly recognized PFAS with the $-C_nF_{2n+1}$ moiety, the OECD/UNEP Global PFC Group proposed to also include substances that contain the moiety $-C_nF_{2n}-$ ($n \geq 1$) as PFAS.² The present study is in line with this proposal. In contrast to the definition by Buck et al. (2011), the present study also includes i) substances where a perfluorocarbon chain is connected with functional groups on both ends, ii) aromatic substances that have perfluoroalkyl moieties on the side chains, and iii) fluorinated cycloaliphatic substances.

More specifically, the present study focuses on polymeric PFAS with the $-CF_2-$ moiety and non-polymeric PFAS with the $-CF_2-CF_2-$ moiety. It does not include non-polymeric substances that only contain a $-CF_3$ or $-CF_2-$ moiety, with the exception of perfluoroalkylethers and per- and polyfluoroalkylether-based substances. For per- and polyfluoroalkylethers and per- and polyfluoroalkylether-based substances, those with a $-CF_2CF_2-$, $-CF_2OCF_2-$ or $-CF_2OCFHCF_2-$ moiety are included.

4.2 Literature sources

The present inventory was started with the risk profiles and risk management evaluations for PFOA, PFOS, PFHxS and their related compounds to obtain an overview of uses of these chemicals.^{21–27} Reports and books that address fluorosurfactants and fluoropolymers in general were also included.^{3,8,34–40,11,13,17,18,30–33} Literature specific to certain use categories was retrieved for more information either on the substances used, or to understand why PFAS are, or were, necessary for a given use. All specific references are cited in the Electronic Supplementary Information 1 (ESI-1).

In addition, databases, patents, information from PFAS manufacturers and scientific studies that measured PFAS in products were examined. These additional sources are described in more detail in the following subsections. The searches were not exhaustive in any of the sources described, and there are still many more reports, scientific studies, patents, safety data sheets and databases with information on the uses of PFAS than the ones cited here or in the ESI-1.

The information in the tables in the ESI-1 from these sources was marked according to its original source. Information from patents (cited in a book, article or report) was marked with “P”, information on PFAS analytically detected in products with “D”, and information on uses or information without additional reference with “U” for “use” (for more details, see below).

4.2.1 Chemical Data Reporting under the US Toxic Substances Control Act—

Manufacturers and importers that produced chemicals in amounts exceeding 25'000 pounds (11.34 metric tons, t) at a site in the US between 2012 and 2015 were obliged to report to the US Environmental Protection Agency (US EPA) in 2016 (data for 2016 to 2019 will be reported in 2020). The data reported in 2016 (available in CSV files) included for each reported substance the name, Chemical Abstracts Service (CAS) registry number and product categories for consumer and commercial uses and sectors, as well as function categories for industrial processing and use. The masses (tonnages) used and exported also had to be reported; however, they are in most cases confidential business information (CBI). The reported data were filtered according to chemical names containing the word “fluoro”. Non-polymeric substances that did not contain the -CF₂CF₂- moiety and polymeric substances that did not contain the -CF₂- moiety subsequently were removed. This left 39 entries where a specific PFAS was applied in a consumer or commercial use, and around 120 entries where a specific PFAS was applied in an industrial processing or use. The entries are labelled with “U” for “use” in the tables in the ESI-1 and ESI-3.

4.2.2 Data from the SPIN database of Denmark, Finland, Norway and Sweden

—The Substances in Preparations in Nordic Countries (SPIN) database contains information on substances from the product registers of Denmark, Finland, Norway and Sweden.⁴¹ There are several cases in which substances do not need to be registered. For example, Denmark, Finland, Norway and Sweden exempt products that come under legislation on foodstuffs and medicinal products from mandatory declaration. Furthermore, the duty to declare products to the product registers does not apply to cosmetic products. In addition, there is in principle no requirement to declare solid processed articles to any of the registers. There is also a general exemption from the duty to declare chemicals in Sweden, Finland and Norway, if the quantity produced or imported is less than 0.1 t per year (in Finland no exact amount is given). Of the Nordic countries, only Denmark and Norway require information on all constituents for most products for which declaration is mandatory. In Sweden, substances that are not classified as dangerous and that make up less than 5 per cent of a product may be omitted from the declaration. In Finland, information on the composition of products is registered from the safety data sheets. Complete information on the exact composition is consequently not necessarily given.

The data that we used in the present study were extracted for us from the SPIN database by an employee of the Swedish Chemicals Agency (KEMI) and the data included only non-confidential information. However, there is also a substantial amount of confidential information in the SPIN database. This is visible when the substances are accessed via the web interface of the SPIN database.⁴¹ It was also pointed out to us that not all substances have available use data due to confidentiality.

The database includes four large data sets with information on uses. Two of the data sets (“UC62” and “National use categories”) contain information on specific use categories, while the other two (“Industrial NACE” and “Industry National”) contain information on sectors of uses. In addition to the use categories and sectors of uses, the data sets also contain information on the quantities of a chemical used in a certain use category or sectors of uses if the reported mass exceeds 0.1 t. The available data cover the time period 2000 to 2017. The four data sets were merged and then (as with the TSCA Inventory data) filtered for chemicals containing the word “fluoro”. Those non-polymeric substances that did not contain the -CF₂CF₂- moiety and polymeric substances that did not contain the -CF₂- moiety subsequently were removed. This left 950 entries. Entries with available data for 2017 were labelled as “current use” (U*) in the tables in the ESI-1 and ESI-3, all other entries with “U” for “use”.

4.2.3 Patents—Another important source of information is the patent literature. Patents were searched for via SciFinderⁿ⁴² (which is the newest version of SciFinder) and Google Patents.⁴³ The patent search in SciFinderⁿ was mostly conducted via keywords and the constraint that the patent must contain a substance with the -CF₂-CF₂- moiety. This can be done in SciFinderⁿ by using the “draw” function. Google Patents was mainly used to search for a full patent text (via the patent number) when SciFinderⁿ only provided the abstract of the patent. The advantage of SciFinderⁿ (which belongs to CAS) is that experts manually curate the substances described in the patents and provide CAS numbers. All substances identified in the patent are visible in SciFinderⁿ together with the patent. Through the patents it was possible to determine in which applications PFAS may be used. While it is not possible to determine whether licenses for a patent have been obtained, the status of the patent (e.g. active, withdrawn, expired, not yet granted) can be determined. Active patents become expensive for their owners over the years. Representatives from CAS informed us that it is very likely that a patent is still in use if it is still paid for after 10 to 15 years.⁴⁴ After 20 years, a patent expires, which means that the invention can be used by others free of cost. Note that many patents cover not just a specific substance, but rather a basic structure to which different functional groups can be attached. The SciFinderⁿ experts give CAS numbers to those substances whose existence has been proven by the registrants. Such a proof can be a physical method or the description in a patent document example or claim. Still, it is not always clear which substances are actually used in practice. Patents were found for many uses, and the patented substances are included in the tables in the ESI-1, labelled with “P” for “patent”.

4.2.4 Information from companies that manufacture or sell PFAS—3M, Chemours, DuPont, F2 Chemicals, Solvay, and other PFAS manufacturers describe on their

webpages which products they make and what these can be used for. Separate factsheets are also available for some of the products, for example, for fluorocarbons from F2 Chemicals,⁴⁵ 3M™Novec™ Engineered Fluids^{46–49} or Vertrel™ fluids from Chemours.⁵⁰ The difficulty with this information is that it is often not specified which substances are contained in the products. Sometimes the safety data sheets provide information about the composition of the products, but in most cases they do not. Dozens of factsheets and safety data sheets were screened for the present study and the information on the PFAS they contained was extracted. However, it was not feasible, in a reasonable amount of time, to examine all factsheets and safety data sheets of the major PFAS manufacturers. The data included in the tables in the ESI-1 are labelled with “U” for “use”.

4.2.5 Studies that measured PFAS in products—There are also numerous individual studies that analysed PFAS in products, for example in fire-fighting foams,^{51–55} building materials,⁵⁶ hydraulic fluids and engine oils,⁵⁷ impregnation sprays,^{58,59} or various other consumer products.^{35,60–65} These studies are important because they show in which products PFAS exist. However, in most studies only a handful of substances were analysed and even for these substances it is not clear whether they were used intentionally, impurities in the actual substances or degradation products. The data included in the tables in the ESI-1 are labelled with “D” for “detected analytically”.

4.2.6 Market reports—A variety of non-verified commercial market reports exist for PFAS. Examples are the Fluorotelomer Market Report, Fluorochemicals Market Report or the Perfluoropolyether Market Report from Global Market Insights.^{66–68} The information from these reports is not included in this study as these reports do not state their information sources and thus cannot be verified.

4.3 Nomenclature

In the present study, a distinction is made between use categories and subcategories. A use category can, but does not necessarily, have subcategories. An example of a use category for PFAS is sport articles; a subcategory under sport articles is tennis rackets.

A distinction is also made between use, function and property. The “use” is the area in which the substances are employed. This can either be the use category or the subcategory. The “function” is the task that the substances fulfil in the use, and the “properties” indicate why PFAS are able to fulfil this function. An example for a use would be chrome plating. In chrome plating, PFAS have the *function* to prevent the evaporation of hexavalent chromium (VI) vapour, because of the PFAS *properties* that lower the surface tension of the electrolyte solution and since the PFAS used are stable under strongly acidic and oxidizing conditions.³

In the present study, the term “individual PFAS” always refers to substances with a CAS number, irrespective of whether they are mixtures, polymers or single substances.

4.4 Classification of use categories

The use categories in the present study were developed and refined throughout the course of the project to have as few well-defined use categories as possible that were not too broad.

Initially, the use categories as defined by Kissa (2001)³ were employed, but they are very specific and thus broader categories were needed to cover the identified uses. Examples of use categories from Kissa (2001) which were assigned to broader categories are “molding and mold release” (in the present study a subcategory under “production of plastic and rubber”), “oil wells” (in the present study a subcategory with a slightly different name under “oil & gas”), and “cement additives” (in the present study a subcategory under “building and construction”). In the course of the project, more use categories were defined as additional uses were added. The use categories in the present study were finally divided into “industrial branches” and “other use categories” to make a distinction between use categories that define broad industrial branches such as the “semiconductor industry” or the “energy sector”, and use categories that are more specific such as “personal care products” or “sealants and adhesives”. Note that some of the “other use categories” may be applied to several of the “industry branches”. For example, “wire and cable insulations” may be applied in “aerospace”, “biotechnology”, “building and construction”, “chemical industry” and others.

Overall, the use categories defined in the present study are very similar to the categories of the SPIN database, although some categories of the SPIN database are more specific (and correspond to subcategories in the present study). Examples of very similar categories are “anti-foaming agents, foam-reducing agents” (SPIN database) and “antifoaming agent” (present study), “construction” (SPIN database) and “building and construction” (present study) or “cleaning/washing agents” (SPIN database) and “cleaning compositions” (present study). Some of the categories in the SPIN database could not be assigned to any of the use categories in the present study because they were too general. Examples are “impregnation”, “surface treatment”, “anti-corrosion materials” or “manufacture of other transport equipment”. Although the substances from these categories are not included in the present study, their quantities appear in Figure 3 and Figure 4 under “various”.

4.5 What kind of information can be found where in this article?

The present study comes with an Appendix that lists the main functions of the PFAS in the use categories and subcategories that we identified. In addition, we indicate which properties of the PFAS are important for the identified function. The Appendix thus contains the main results of the present study in a condensed form and is therefore part of the main paper and not part of the ESI.

The ESI of the present study is divided into three parts. ESI-1 is a comprehensive document with 250 pages. It is available as a pdf, but can also be provided upon request as an MS Word document. ESI-1 is intended to be used as a reference document and contains a detailed description of all uses that were collected here as well as the PFAS employed in these categories with names, structural formulas and CAS numbers.

In addition, there is an MS Excel workbook (ESI-2) that contains all PFAS that appear in ESI-1. This workbook has a worksheet for each of the most common PFAS groups such as perfluoroalkyl acids (PFAA), perfluoroalkane sulfonyl fluoride (PASF)-based substances, or fluorotelomer-based substances and, thus, offers a good overview of the described PFAS. A list of what is included in the different worksheets is provided in the first worksheet. ESI-2 is

primarily intended as a reference for readers who do not have access to SciFinderⁿ or other chemical databases or who just want to look up the name or structural formula for a specific CAS number. In addition to name, CAS number, and structural formula, ESI-2 also contains the identified uses of each PFAS. In contrast to ESI-1, ESI-2 assigns the uses to the PFAS (and not the PFAS to the uses).

The third part of the ESI (ESI-3) is also an Excel workbook that provides a separate worksheet for each use category. These worksheets list the PFAS from the ESI-1 with the names, CAS numbers, elemental compositions, and exact monoisotopic masses of the substances. Our intention is that the lists can be added to accurate mass spectrometry libraries and thus help to identify unknown PFAS more easily in the future. For this purpose, it would be helpful to connect the CAS numbers in the ESI-3 with e.g. the Norman SusDat ID of the NORMAN Substance Database⁶⁹ and perhaps to commercial mass spectrometry libraries in the future.

5 Results

In the present study, more than 200 uses in 64 use categories were identified for more than 1400 individual PFAS. This means that the present study encompasses five times as many uses (counted as use categories plus subcategories) than included by Kissa (2001)³. This shows that the present study goes much further than simply updating this previous work. The following subsections describe the identified use categories and substances and show and discuss the most important use categories in terms of quantities used, based on the data of the SPIN database and the Chemical Data Reporting database under the TSCA.

5.1.1 In which use categories have PFAS been employed and for which function?

The Appendix to the present study sets forth the use categories identified and answers the question of why PFAS were employed for a specific use. The use categories identified in this study are divided into “industry branches” and “other use categories”, as listed in Table 1. In total, 86 uses within the 20 industry branches and 124 uses within the 44 other use categories were identified. Among the use categories, medical utensils and the semiconductor and automotive industries have the largest numbers of subcategories. About one-seventh of the subcategories have been identified by patents, and one-twentieth by studies that have measured PFAS in products (see ESI-3). The remaining categories have been mentioned previously in other publications.

The identified uses included many uses not previously described in the scientific literature on PFAS. Some examples of those uses are PFAS in ammunition, climbing ropes, guitar strings, artificial turf, and soil remediation. Also, additional subcategories of PFAS in already described use categories such as in the semiconductor industry were identified. For example, in addition to the subcategories etching agents, anti-reflective coatings, or photoresists, PFAS are also employed for wafer thinning (patent US20130201635 from 2013)⁴² and as bonding ply in multilayer printed circuit boards (patent WO2003026371 from 2003) in the semiconductor industry.⁴² In the energy sector, PFAS are known to be employed in solar collectors and photovoltaic cells, and in lithium-ion, vanadium redox, and zinc batteries. In addition, fluoropolymers are also used to coat the blades of wind mills²⁰

and PFAS can be employed in the continuous separation of carbon dioxide in flue gases (patent CN106914122 from 2017)⁴² and as heat transfer fluids in organic Rankine engines.⁴⁵ These examples all show that the uses of PFAS are much more extensive than so far reported in the scientific literature.

Altogether, we were able to identify almost 300 functions of PFAS (listed in the Appendix). Examples of those functions are foaming of drilling fluids, heat transfer in refrigerants, and film forming in AFFFs. The properties that led to the use of the PFAS are also identified.

These include among others: ability to lower the aqueous surface tension, high hydrophobicity, high oleophobicity, non-flammability, high capacity to dissolve gases, high stability, extremely low reactivity, high dielectric breakdown strength, good heat conductivity, low refractive index, low dielectric constant, ability to generate strong acids, operation at a wide temperature range, low volatility in vacuum, and impenetrability to radiation. In the Appendix, these properties are assigned to the specific uses (and functions).

5.1.2 Which PFAS have been and are used for a certain category?

The ESI-1 to the present study describes or lists those PFAS that have been or are currently employed (or have been patented) for each individual use. In total we have found uses for more than 1400 individual PFAS. About one third of these PFAS are also listed in the OECD list.² This shows that many of the PFAS listed in the present study are on the market, and that many more PFAS that are not on the OECD list may be used or are already being used.

Due to the great variety of uses and the large number of PFAS, it is difficult to make generic statements here. Overall, it was found that the number of different PFAS identified for a certain use mostly depends on the properties required for that use. PFAS have diverse properties. Some properties, or combinations of properties, are only found in specific groups of PFAS. For example, perfluorocarbons seem to be particularly well suited as vehicles for respiratory gas transport due to the high solubility of oxygen therein. Similarly, anionic PFAS (largely those with a sulfonic acid group) are used as additives in brake and hydraulic fluids due to their ability to alter the electrical potential of the metal surface and thus, protect the metal surface from corrosion through electrochemical oxidation. In contrast, there are also properties that are shared by many different groups of PFAS. Many PFAS are very stable and many can reduce the surface tension of aqueous solutions considerably, improving wetting and rinse-off. Therefore, a typical use in which many different types of PFAS have been or are used is in cleaning compositions. The patented, analytically detected and employed PFAS for this use include PFAAs, PASF-based substances, and fluorotelomer-based substances (see ESI-1 Section 2.6.1). A similar variety of PFAS (90 substances in total) were identified in patents for photographic materials to control surface tension, electrostatic charge, friction, adhesion, and dirt repellency.

This array of different PFAS may be surprising, but it shows that some properties of PFAS are shared across many PFAS groups. The large number of patented PFAS for the same use raises the question of whether some of these substances offer better performance than others, or whether it does not really matter which PFAS are employed. The latter would indicate that manufacturers can invent new PFAS quite easily to avoid license fees for patents of other manufacturers.

For the majority of uses, however, far fewer PFAS were identified. Figure 1 highlights the use categories grouped according to the number of PFAS identified. It should be noted that the number of PFAS reflects the number that we have identified in the present study, and not the number of substances on the market or available for a certain use. For half of the use categories, we have identified more than 20 PFAS, and for seven use categories more than 100 PFAS. The use categories with more than 100 identified PFAS are “photographic industry”, “semiconductor industry”, “coatings, paints and varnishes”, “fire-fighting foams”, “medical utensils”, “personal care products”, and “printing”. There are also two categories where no specific substances were identified. These are “ammunition” and “nuclear industry”.

The most frequently identified PFAS in our literature search are non-polymeric fluorotelomer-based substances, followed by non-polymeric PASF-based substances and PFAAs. Other identified non-polymeric substances are perfluoroalkyl phosphinic acids (PFPIA)-based substances, perfluoroalkyl carbonyl fluoride (PACF)-based substances, cyclic PFAS, aromatic substances with fluorinated side-chains, per- and polyfluoroalkyl ethers, hydrofluoroethers, and other non-polymers. Polymeric substances include fluoropolymers, side-chain fluorinated polymers, and perfluoropolyethers (see also ESI-2). There is also a variety of substances in the groups themselves, especially among the non-polymeric fluorotelomer-based and PASF-based substances. For many of the substances, only one use (or patent for a use) was identified. For example, one use (or patent) was assigned to 372 fluorotelomer-based substances, two uses (or patents) to 39 fluorotelomer-based substances and three or more uses to 33 fluorotelomer-based substances. The reason why so many PFAS have only one identified use may be that not all the uses were identified for all PFAS. But it also seems that many patents contain “new” PFAS because they work just as well as the established ones.

In contrast to the many PFAS with only one assigned use, some PFAS have many uses. ESI-2 illustrates this point: of the 2400 links between individual PFAS and assigned uses, 15 PFAS have been assigned to 10 or more uses (see Table 2 and Figure 2). The exact use counts are not important per se, because there may be more uses for these PFAS that have not been included in the present study, but they demonstrate that some PFAS are employed more frequently than others. It has to be noted that the three fluoropolymers in Table 2 are quite different from the other PFAS in the list, as they represent possibly dozens or hundreds of technical products with different grades and molecular sizes.

Of the 2400 links between individual PFAS and assigned uses, around 42% of the links were obtained from patents, 27% from studies that detected PFAS in products and 31% from publications that reported actual uses.

5.1.3 What is the magnitude of the uses and can uses be ranked by quantity?

To prioritize PFAS uses in the search for alternatives, it is key to know for which uses PFAS were employed the most. Wang et al.^{12,14,70} published global emission inventories for C₄-C₁₄ PFCAs and C₆-C₁₀ PFSAAs. For PFSAAs and their precursors, the highest amounts were identified for the use in “apparel/carpet/textile”, followed by “paper and packaging”, “performance” and “after-market/consumers”. There is also information on the quantities of

individual fluoropolymers used.^{30,71} However, a coherent data set with data covering a wide range of uses and at the same time a wide range of PFAS has not been available so far. The following two subsections will show the magnitude of the uses based on the data from the SPIN database and the Chemical Data Reporting database under the TSCA. Data from REACH that would have covered more countries than the data from the SPIN database are not shown, because the tonnage bands in REACH refer to the substances and not to use categories. Accordingly, only in those cases where a substance has only one use would it have been possible to obtain useful information for this study, which would have created a lot of uncertainty in the data.

Data from the SPIN database—Figure 3 highlights the total, non-confidential amounts of PFAS employed in the different use categories in Sweden, Finland, Norway and Denmark between 2000 and 2017.⁴¹ It should be noted that the data from these Nordic countries may not be representative of other parts of the world. One reason is that only non-confidential data are included, that substances in foodstuffs, medicinal products, and cosmetics do not have to be declared (see Section 2.2.2) and that there is no fluoropolymer or PFAS production in these countries. Nevertheless, the data from the SPIN database provide a first indication of which uses of PFAS have been important in the last 20 years in this region.

The data illustrate that a large amount of PFAS was used in the production of plastic and rubber, the electronics industry, and coatings and paints (Figure 3). The production of plastic and rubber does not include the production of fluoropolymers. Between 2000 and 2017, more than 3000 t of PFAS were used in the three categories previously mentioned. Around 1500 t of PFAS were used in building and construction and in lubricants and greases and around 1200 t of PFAS in the chemical industry, respectively. All other uses were below 1000 t.

Non-polymers were mainly used in the electronic industry, in buildings and construction, electricity, gas, steam and air conditioning supply, and flame retardants and extinguishing agents. Of the 6,300 t of non-polymers used in the Nordic countries between 2000 and 2017, 5,650 t (90%) were the hydrofluorocarbon (and greenhouse gas) 1H-pentafluoroethane (CAS No. 354–33-6). More than 70% (470 t) of the remaining non-polymeric PFAS were used in flame retardants and extinguishing agents. The SPIN database has a combined category for these two use categories, so it was not possible to distinguish them.

Polymers were mostly used in the production of plastic and rubber, coatings and paints, lubricants and greases, and in the chemical industry. At least 13,700 t of polymers were used in the Nordic countries between 2000 and 2017, and 10,000 t (73%) of this was PTFE. This percentage is a bit higher than the numbers published recently by AGC, which stated that 53% of the 320'000 t of fluoroplastics consumed worldwide in 2018 was PTFE.⁷¹

Data from the Chemical Data Reporting under the TSCA—Under the TSCA, the Chemical Data Reporting lists under “volume” the amount of a substance in a certain sector and function category or product category. However, more than 80% of the volume entries in the Chemical Data Reporting database are CBI. The certainty of the available information is therefore low, but a general statement is still possible. Table 3 highlights the non-

confidential data on used and exported amounts of PFAS for the different uses based on the data reported in 2016.

The amount of used and exported PFAS was largest for functional fluids in “electrical equipment, appliance, and component manufacturing” and functional fluids in “machinery manufacturing”. The exact same amounts in the two use categories are no coincidence but come from the declaration that 50% of the total amount was used for “electrical equipment, appliance, and component manufacturing” and 50% for “machinery manufacturing”. 1H-pentafluoroethane (CAS No. 354–33-6) accounted for 100% of the total amount in both cases. The high amount of 1H-pentafluoroethane employed as functional fluids in “electrical equipment, appliance, and component manufacturing” confirms the data from the SPIN database that the electronic industry is an important purchaser of this PFAS. The high amount of “functional fluids” in “machinery manufacturing” could be related to refrigerants, air conditioners or other uses, but due to the broadness of the use category, nothing definite can be concluded. Also, as it was found for Europe, no data were available for amounts of non-polymeric PFAS used as processing aids under fluoropolymer production in the US, which may be expected to be a considerable contributor. The same amounts of “finishing agent” in “paint and coating manufacturing” and “paper manufacturing” are again from the declaration 50% and 50%.

6 Discussion

6.1 Scope of the present study and uncertainties

6.1.1 Scope of the present study and uncertainties related to use categories

—The present study covers many past and current uses of PFAS. The inventory is not exhaustive and it also contains uncertainties. One area of uncertainty comes from harmonizing entries to the use categories from different sources. This is especially relevant when comparing use amounts, because the reported amounts from the different databases are related to more or less specific use categories that may be defined differently in different databases. Although not quite as critical, this was also a relevant point for the ESI-1. Here, information on specific uses of PFAS was assigned to subcategories and information on broader uses to the main use categories. Still, there were some use categories (especially from the Chemical Data Reporting database under the TSCA) that were so broad that we were not able to assign them to any category in our list. Examples are “surface active agents in all other basic inorganic chemical manufacturing”, or “functional fluids in wholesale and retail trade”. The PFAS listed under such categories and their quantities were not, therefore, considered in the present study.

Another area of uncertainty originates from unidentified uses. We found, for example, that PFAS are used in climbing ropes.⁷² It therefore cannot be excluded that they are also used in climbing harnesses, but no information was found on this. We did not have the capacity to conduct interviews with industry representatives who might have revealed additional information. We were similarly limited when it came to evaluating the copious amount of information about PFAS uses, for example in reports, scientific papers and patents. Therefore, not all PFAS uses might have been identified in the present study.

In the case of patents in particular, a great amount of information is available, but it should be noted that only some of the PFAS included in patents currently are likely used on the market. In addition to these uncertainties, some of the use category-specific information in the SPIN database is CBI, meaning that we may have not seen all categories. It would be desirable if such information was no longer confidential in the future, in order to inform consumers, users, and regulators.

Nevertheless, the SPIN database is a very valuable source of information and it would be much easier to compile such inventories of uses if other countries had product registries like the Nordic Countries. Without such product registries, the compilation of uses and the substances used remains difficult and lengthy. It would also be advantageous if the uses under REACH were more precisely named. Current categories like “processing aids at industrial sites” or “manufacture of chemicals” are very broad and thus difficult to include.

An important question is whether the majority of the use categories is covered in the present study or whether important use categories are still missing. It is difficult to answer such a question quantitatively, but a qualitative indication is possible when the use categories of the SPIN database are compared to the categories that were already identified. Both categories match very well; only three categories had to be added to accommodate data from the SPIN database in the ESI-1 appropriately. These three categories were “machinery and equipment”, “manufacture of basic metals” and “manufacture of fabricated metal products”. In the latter two categories, it is not clear what PFAS are used for and why. “Manufacture of basic metals” could be linked to mining, and “manufacture of fabricated metal products” could include the coating of metal surfaces e.g. for knives in food production. But both categories are so broad that it is unclear what is really meant. The category “machinery and equipment” could include wire and cable insulations and lubricants. It is known that PFAS are used in both of these categories. However, “machinery and equipment” could also contain other uses of which we are not aware. The Chemical Data Reporting under TCSA mentions the use of PFAS in or as functional fluids in the sector “machinery manufacturing”. This is still relatively vague and could include heat transfer agents, lubricants or any other fluid used in machines. However, with the exception of these three categories, all specific information from the SPIN database could be classified very well into the existing categories of the present study. Overall, we assume that there are no major gaps in the general use categories. However, it is quite possible that subcategories are missing. Among the uses of which we are aware, there may also be some uses where PFAS are no longer employed.

To improve the list of uses in the future, there are several possibilities. Firstly, one could try to get access to product registries of as many countries as possible. Unfortunately, not all product registers are as easily accessible as those of the Nordic countries and many developing countries do not have such a register. The list could also be extended with information from REACH registration dossiers. These dossiers include information of uses and tonnage bands expected to be used at the time of registration. Interviews with manufacturers of products could also generate more information. However, we know from experiences with past projects that manufacturers often want the interviewers to sign a non-disclosure agreement before the interview which prevents using the information obtained in

publications. The information from such interviews could still provide some indication as to what kind of information to look for in the public domain. The same is true for the market reports. They can give a clue for what to look for in the public domain (given that they often contain no references). A discouraging factor for researchers who may want to use market reports as data sources is that the companies who generate them often sell them for extortionate sums (i.e. several thousand US dollars) and that most of them are not based on thorough research.⁷³ Another approach could be to use artificial intelligence to systematically search product sales/industry magazines for words or phrases, such as ‘fluor’.

6.1.2 Uncertainties related to substances—Uncertainties also exist regarding the substances identified for a particular use. Some of these uncertainties are already discussed in the Methods section: not all registered patents are used on the market, not all substances included in a patent are used in practice, and substances that have been detected analytically in products might be impurities in or degradation products of the actual substances. In addition, we only looked for examples of PFAS and the lists are by no means complete. Also, the substances included in the present study from the SPIN database are not substances in articles, but substances in preparations. The substances listed in ESI-1 under U or U* are also those that were intentionally used in the products. However, impurities, reaction products upon mixing the ingredients, and degradation products of the intentionally added PFAS might also be present in products. Industrial blends are rarely pure, but can be only 80% of the registered substance, so 20% can be impurities, reaction by-products, degradation products etc.

In addition, industry tends to evolve around consumer needs, costs savings, and external factors such as regulatory oversight, and substances used today may no longer be relevant tomorrow. A better overview of the substances being used could be obtained if manufacturers had to list which substances are contained in a product in the safety data sheets. However, except for a few instances (e.g. when uses are authorized for food contact materials in Germany), this is not the case and patents are therefore often the only way to find out what a product (might) contain. A better overview of the substances used would also be possible - at least for the US - if substances with tonnages below the reporting threshold of 11.34 t were also included in the TSCA Chemical Data Reporting database. In the EU, it would be helpful if the registration dossiers under REACH as well as other legislations not covered by REACH were updated regularly with a more detailed breakdown of which quantities of the substances are used, and in which applications.

6.1.3 Uncertainties related to quantities—The third part of the present study - identifying the key use categories in terms of quantities - also contains various uncertainties. The data from the SPIN database only represent the Nordic countries, while many industry branches have a greater presence in other countries or regions of the world than in the Nordic countries. Additionally, many of the volumes in the SPIN database are CBI. The SPIN database does also not include all uses. An example is that foodstuff, and hence food packaging is not reported to the SPIN database, which possibly could explain why ‘packaging’ which was significant in the OECD study, did not stand out in the SPIN survey. Similar, non-polymeric PFAS such as ADONA and GenX are used as processing aids during

fluoropolymer production. The quantities of these processing aids are not captured in the statistics of the SPIN database since this activity is not ongoing in Scandinavia. However, the considerable amounts of fluoropolymers produced in Europe of about 52,000 t per year, and about 230,000 t globally lets us believe that a considerable amount of PFAS is used in this use category in addition to what is shown in Figure 3 under “Chemical industry”.

The data from the US are only partly helpful, because a large part of the reported amounts is CBI and only substances above 11.34 t at a single site have been reported. Although in some use categories large quantities of PFAS are employed, it is difficult to compare the amounts, because the unreported amounts due to CBI could be much larger than the non-confidential reported amounts. The extent of the uncertainties in the SPIN database due to the CBI cannot be estimated with the available data, but could be large. It would be helpful if regulatory agencies, such as the US EPA, could create a ranking of the PFAS uses (without stating any numbers) based on the entire datasets they have collected.

6.2 Findings of the present study with regard to uses

The present study is a renewed and expanded effort to systematically compile a wide range of known as well as many overlooked uses of PFAS. Besides describing the uses of PFAS, we also endeavoured to explain which functions the PFAS fulfil in these uses. The descriptions of the functions and properties of the PFAS employed are especially important for determining “non-essential” use categories and identifying alternatives for those uses currently considered “essential”.

However, as can be seen from the question marks in the Appendix it was not always possible to determine why PFAS were used or needed in a particular case. In 4% of the cases we could not clarify which function the PFAS fulfil in the use category or subcategory, and in 21% of the cases we could not clarify which property is needed to fulfil the mentioned function. For example, we do not know exactly why PFAS are employed in the ventilation of respiratory airways, in brake-pad additives, and in resilient linoleum. It would be important to engage with product manufacturers to understand what function the PFAS have, in order to identify appropriate replacements. Some of the uses might also be judged as “non-essential” and thus could be eliminated or discontinued.

Our study also shows that in several areas where large quantities of PFAS are employed, discussions concerning alternatives are still not underway in the public domain. In general, in recent years the focus in the search for alternatives for PFAS has been on fire-fighting foams,^{74,75} paper and packaging,^{76,77} and textiles.^{78–81} This focus was certainly appropriate, because these are uses where PFAS are in direct contact with the environment (fire-fighting foam) or with humans (food packaging, textiles). However, our study shows that PFAS are also used widely in the production of electronics and in machinery manufacturing, and at least in the Nordic countries in the production of plastic and rubber and in paints and coatings. Measuring and/or reporting emissions along the life cycles of these uses, and the search for alternatives in these use categories should therefore also be prioritized. These uses could for instance be included in the activities for which data have to be reported under the European Pollutant Release and Transfer Registry.

It would also be important to look for alternatives in industry branches that use smaller amounts of PFAS or that are not included in the SPIN database or Chemical Data Reporting database, but produce large amounts of wastewater, exhaust or solid waste containing PFAS. More information is needed to prioritize the various use categories, but potentially worrisome categories where environmental contamination has been documented are fluoropolymer production,^{82–84} the semiconductor industry,^{85,86} and metal plating.⁸⁷

Other uses where humans are in direct contact with PFAS and that have not yet gained much attention regarding alternatives include: personal care products and cosmetics, pesticides, pharmaceuticals (including eye drops), printing inks, and sealants and adhesives. A search for alternatives would also be important here.

6.3 Findings of the present study with regard to substances

We can ascertain from the SPIN database that two PFAS, 1H-pentafluoroethane and PTFE, account for 75% of the quantities used in the Nordic countries. One explanation is that PTFE and 1H-pentafluoroethanes are not used as additives, but as the main products. For example, entire roof structures or coatings are made of out of PTFE.²⁸ For 1H-pentafluoroethane (also known as HFC-125), one of the main uses is as a heat transfer fluid and cooling agent,^{41,88} which could explain the large quantities of that substance used.

Other PFAS used as surfactants are utilized in much smaller quantities probably due to their high market price. They may therefore not appear (or at least not in high amounts) in databases such as the SPIN database or the Chemical Data Reporting database, which only report substances (or masses) above a certain threshold. PFAS used in articles, which are manufactured mainly in Asia or other countries outside the EU or the US, may also not appear in large amounts in the SPIN or Chemical Data Reporting database, simply because the databases do not contain information on PFAS in articles. The PFAS that we have listed as examples in ESI-1 are mainly those used in Europe or North America. A recent publication⁸⁹ lists e.g. seventy PFAS from the Inventory of Existing Chemical Substances Produced or Imported in China (IECSC) that are not in the North American and European chemical inventories. These PFAS are also not in our inventory, because no information on their intended use was provided.

Concerning the currently used PFAS, it was thought - due to the voluntary phase out of all PFAS products derived from perfluorooctane sulfonyl fluoride by 3M⁹⁰ and the voluntary PFOA Stewardship Program in which eight companies agreed to phase out 95% of uses by 2015⁹¹ - that at least ammonium perfluorooctanoate and potassium perfluorooctane sulfonate are no longer in use in the US. However, other companies have not been prevented from taking over the market, and there has been very limited enforcement of the actual phase-out through regulation. A recent article revealed that PFAS that can break down into PFOA and PFOS are still in use in the US.⁹² Those uses include coatings for medical devices, apparel, and other industries, and equipment in pharmaceutical companies. PFAS that can break down into PFOA and PFOS are also still used in semiconductor and electronics companies.⁹²

6.4 Use and implications of the present study

The large number of uses that exist for PFAS, together with the large number of individual substances, makes their regulation and eventual phase-out very challenging. The approach of allowing PFAS only in “essential uses”, as suggested for example in the EU strategy paper “Elements for an EU-strategy for PFAS”,⁵ will not be easy to implement if regulators try to assess all uses individually. An alternative approach could be to deem all PFAS uses as “non-essential” unless producers or users make a convincing case for essentiality, and that authorities set a sunset clause on “essential uses”.

The number of use categories for both non-essential and essential cases is critical to estimate the amount of work that would need to be done, for example, to prepare a restriction proposal under REACH (as planned by five European countries²⁹). The descriptions in the present study of where and why PFAS are used can be used to provide an overview of the uses and may also facilitate an understanding of what alternatives need to be developed and with which priority.

The information in this study may also help regulators and scientists determine which PFAS to measure in contaminated areas, in humans in surrounding communities and in products. To facilitate the identification of PFAS in various matrices, we provide the ESI-3 file, which contains for each use category the name, CAS number, and exact monoisotopic mass of the substance. The ESI-3 file also includes information on whether PFAS were identified in a patent, detected analytically in products or reported as employed substances. Laboratories could use modern analytical methods such as suspect-screening analysis utilising accurate mass spectrometry to identify novel and emerging PFAS listed in ESI-3.^{51,93} Patented substances may be less likely to be on the market and could be excluded or given a lower priority or weighting in suspect screening workflows. Similar lists (such as the ESI-3) are provided by the OECD/UNEP Global PFC Group,² Zhang et al. (2020),⁸⁹ the US EPA, the NORMAN Substance Database⁶⁹ and others. An overview is provided under https://comptox.epa.gov/dashboard/chemical_lists. However, only a few of these lists also contain information on uses.

The ESI-3 may also be valuable for identifying sources of PFAS in the environment. Some uses may impart characteristic PFAS “fingerprints” (i.e. PFAS contamination patterns) to environmental samples that could be used to identify a source, e.g. through statistical methods.⁹⁴ On the other hand, many environments will be impacted by multiple sources and such fingerprinting methods could be challenging in practice.

7 Conclusions

The present study is the first of its kind to systematically compile a wide range of known as well as poorly documented uses of PFAS. The compilation is not exhaustive, but it is still possible to demonstrate that PFAS are used in almost all industry branches and in many consumer products. Some consumer products even have multiple applications of PFAS within the same product. A cell phone for example contains fluoropolymer wiring, PFAS in the circuit boards/semiconductors, and a screen coated with a fingerprint-resistant fluoropolymer. The search for alternatives is therefore a very challenging and extensive task.

The data in the present study can help prioritize the search for alternatives and a matching database of viable alternatives to PFAS would be a logical progression of the present study. It would also be helpful if environmental protection agencies, for example the US EPA, could create a ranking of PFAS uses (without providing tonnages) based on the data they have collected. A ranking without exact figures would still be better than the current situation, in which very little is known about the quantitatively most important use categories due to CBI. The TSCA reform in the US was unfortunately unsuccessful in reducing industry's excessive use of CBI. Even though CBI may protect a specific industry's business, it results in overall less protection for consumers, users, and workers from the chemicals. Even regulators are left in the dark about volumes, use categories, and PFAS used, which limits their ability to assess and prevent harm to humans and the environment.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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10: Appendix

Table 4:

Overview of the uses of PFAS, the function of the PFAS in the uses and the properties of the employed PFAS that make them valuable for this application.

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
<u>Industry branch</u>		
Aerospace		
- Phosphate ester-based brake and hydraulic fluids	corrosion protection	altering the electrical potential at the metal surface
- Gyroscopes	flotation fluids in gyroscopes	?
- Wire and cable	high-temperature endurance, fire resistance, and high-stress crack resistance	non-flammable polymers, stable
- Turbine-engine	use as lubricant	corrosion resistant, stable, non-reactive, operate at a wide temperature range
- Turbine-engine	use as elastomeric seals	operate at a wide temperature range

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Thermal control and radiator surfaces	reject waste heat	survival over a wide operating temperature range, low solar absorbance, high thermal emittance, and freedom from contamination by outgassing
- Coating	protect underlying polymers from atomic oxygen attack	non-reactive, very stable
- Propellant system	elastomers compatible to aggressive fuels and oxidizers	non-reactive, very stable
- Jet engine/satellite instrumentation	use as lubricant	long-term retention of viscosity, low volatility in vacuum and their fluidity at extremely low temperatures
Biotechnology		
- Cell cultivation	supply of oxygen and other gases to microbial cells	great capacity to dissolve gases
- Ultrafiltration and microporous membranes	prevent bacterial growth	?
Building and Construction		
- Architectural membranes e.g. in roofs	resistance to weathering, dirt repellent, light	oleophobic and hydrophobic, low surface tension, beneficial weight-to-surface ratio
- Greenhouse	transparent to both UV and visible light, resistant to weathering, dirt repellent	oleophobic and hydrophobic, low surface tension
- Cement additive	reduce the shrinkage of cement	?
- Cable and wire insulation, gaskets & hoses	high-temperature endurance, fire resistance, and high-stress crack resistance	non-flammable polymers, stable
Chemical industry		
- Fluoropolymer processing aid	emulsify the monomers, increase the rate of polymerization, stabilize fluoropolymers	fluorinated part is able to dissolve monomers, non-fluorinated part is able to dissolve in water
- Production of chlorine and caustic soda (with asbestos diaphragms cells)	binder for the asbestos-fibre-based diaphragms	?
- Production of chlorine and caustic soda (with fluorinated membranes)	stable membrane in strong oxidizing conditions and at high temperatures	stable, non-reactive
- Processing aids in the extrusion of high- and liner low-density polyethylene film	eliminate melt fracture and other flow-induced imperfections	low surface tension
- Tantalum, molybdenum, and niobium processing	cutting or drawing oil	non-reactive, stable
- Chemical reactions	inert reaction media (especially for gaseous reactants)	non-reactive, stable
- Polymer curing	medium for crosslinking of resins, elastomers and adhesives	?
- Ionic liquids	raw materials for ionic liquids	?
- Solvents	dissolve other substances	bipolar character of some of the PFAS
Electroplating (metal plating)		
- Chrome plating	prevent the evaporation of chromium (VI) vapour	lower the surface tension of the electrolyte solution, very stable

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
		in strongly acidic and oxidizing conditions
- Nickel plating	non-foaming surfactant	low surface tension
- Nickel plating	increase the strength of the nickel electroplate by eliminating pinholes, cracks, and peeling	low surface tension
- Copper plating	prevent haze by regulating foam and improving stability	low surface tension
- Tin plating	help to produce a plate of uniform thickness	low surface tension
- Alkaline zinc and zinc alloy plating		
- Deposition of fluoropolymer particles onto steel	supported by fluorinated surfactants	cationic and amphoteric fluorinated surfactants impart a positive charge to fluoropolymer particles which facilitates the electroplating of the fluoropolymer
Electronic industry		
- Dielectric fluids	separation of high voltage components	high dielectric breakdown strength, non-flammable
- Testing of electronic devices and equipment	inert fluids for electronics testing	non-reactive
- Heat transfer fluids	cooling of electrical equipment	good heat conductivity
- Solvent systems and cleaning	form the basis of cleaning solutions	non-flammable, low surface tension
- Carrier fluid/lubricant deposition	dissolve and deposit lubricants on a range of substrates during the manufacturing of hard disk drives	?
- Etching of piezoelectric ceramic filters	etching solution	acidic
Energy sector		
- Solar collectors and photovoltaic cells	high vapour barrier, high transparency, great weatherability and dirt repellency	oleophobic and hydrophobic, low surface tension
- Photovoltaic cells	adhesives with PFAS hold mesh cathode in place	lower the surface tension of the adhesive
- Wind mill blades	coating	high weatherability
- Coal-based power plants	polymeric PFAS filter remove fly ash from the hot smoky discharge	stable, non-reactive
- Coal-based power plants	separation of carbon dioxide in flue gases	lower the surface tension of the aqueous solution
- Lithium batteries	binder for electrodes	almost no reactivity with the electrodes and electrolyte
- Lithium batteries	prevent thermal runaway reaction	good heat absorption of first layer and good heat conductivity of second layer
- Lithium batteries	improve the oxygen transport of lithium-air batteries	great capacity to dissolve gases
- Lithium batteries	electrolyte solvents for lithium-sulfur batteries	bipolar character of some of the PFAS
- Ion exchange membrane in vanadium redox batteries	polymeric PFAS are used as membranes	resistance to acidic environments and highly oxidizing species

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Zinc batteries	prevent formation of dendrites, hydrogen evolution and electrode corrosion due to adsorption onto the electrode surface	low surface tension, non-reactive
- Alkaline manganese batteries	MnO ₂ cathodes containing carbon black are treated with a fluorinated surfactant	?
- Polymer electrolyte fuel cells	polymeric PFAS are used as membranes	ion conductance
- Power transformers	cooling liquid	good heat conductivity
- Conversion of heat to mechanical energy	heat transfer fluids	good heat conductivity
Food production		
- Wineries and dairies	final filtration before bottling with polymeric PFAS	resist degradation
Machinery and equipment		
?	?	?
Manufacture of metal products		
- Manufacture of basic metals	?	?
- Manufacture of fabricated metal products	?	?
- Treatment of coating of metal surfaces	promote the flow of metal coatings, prevent cracks in the coating during drying	lower the surface tension of the coating
- Treatment of coating of metal surfaces	corrosion inhibitor on steel	non-reactive
- Etching of aluminium in alkali baths	improving the efficient life of the alkali baths	?
- Phosphating process for aluminium	fluoride-containing phosphating solutions help to dissolve the oxide layer of the aluminium	?
- Cleaning of metal surfaces	disperse scum, speed runoff of acid when metal is removed from the bath, increase the bath life	?
- Water removal from processed parts	solvent displacement	low surface tension
- Electroless plating of copper	disperses the pitch fluoride in the plating solution	low surface tension
Mining		
- Ore leaching in copper and gold mines	increase wetting of the sulfuric acid or cyanide that leaches the ore	low surface tension
- Ore leaching in copper and gold mines	acid mist suppressing agents	low surface tension
- Ore floating	create stable aqueous foams to separate the metal salts from soil	low surface tension
- Separation of uranium contained in sodium carbonate and/or sodium bicarbonate solutions by nitrogen floatation	improve the separation	?
- Concentration of vanadium compounds	destruction of the mineral structure, increases the specific surface area and pore channel thus facilitating vanadium leaching	acidity
Nuclear industry		

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Lubricants for valves and ultracentrifuge bearings in UF6 enrichment plants	PFAS are used as the lubricants	stable to aggressive gases
Oil & Gas industry		
- Drilling fluid	foaming agent	low surface tension
- Drilling - insulating material for cable and wire	polymeric PFAS are used as insulating material	withstand high temperatures
- Chemical driven oil production	increase the effective permeability of the formation	low surface tension
- Chemical driven oil production	foaming agent for fracturing subterranean formations	low surface tension
- Chemical driven gas production	change low-permeability sandstone gas reservoir from strong hydrophilic to weak hydrophilic	hydrophobic and oleophobic properties
- Chemical driven gas production	eliminate reservoir capillary forces, dissolve partial solid, dis-assemble clogging, increase efficiency of displacing water with gas	lower surface tension of the material
- Oil and gas transport	lining of the pipes is made out of polymeric PFAS	non-reactive (corrosion resistant)
- Oil and gas transport	reduce the viscosity of crude oil for pumping from the borehole through crude oil-in-water emulsions	hydrophobic and oleophobic properties
- Oil and gas storage	aqueous layer with PFAS prevents evaporation loss	lower the surface tension of the aqueous solution
- Oil and gas storage	floating layer of cereal treated with PFAS prevents evaporation loss	low surface tension
- Oil containment (injection a chemical barrier into water)	prevents spreading of oils or gasoline on water	?
- Oil and fuel filtration	polymeric PFAS are used as membranes	non-reactive (corrosion resistant)
Pharmaceutical industry		
- Reaction vessels, stirrers, and other components	use of polymeric PFAS instead of stainless steel	?
- Ultrapure water systems	polymeric PFAS are used as filter	low surface tension
- Packaging	polymeric PFAS form moisture barrier film	hydrophobic
- Manufacture of "microporous" particles	processing aid	?
Photographic industry		
- Processing solutions	antifoaming agent	lower the surface tension of the solution
- Processing solutions	prevent formation of air bubbles in the solution	lower the surface tension of the solution
- Photographic materials, such as films and papers	wetting agents, emulsion additives, stabilizers and antistatic agent	low surface tension, low dielectric constant
- Photographic materials, such as films and papers	prevent spot formation and control edge uniformity in multilayer coatings	low surface tension
- Paper and plates	anti-reflective agents	low refractive index
Production of plastic and rubber		

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Separation of mould and moulded material	mould release agent	hydrophobic and oleophobic properties
- Separation of mould and moulded material	reduce imperfections in the moulded surface	low surface tension
- Foam blowing	foam blowing agent	low surface tension
- Polymer processing aid	increase processing efficiency and quality of polymeric compounds	lower the surface tension of the polymeric products
- Etching of plastic	wetting agent	low surface tension
- Production of rubber	antiblocking agent	low surface tension
- Fluoroelastomer formulation	additive in curatives	?
Semiconductor industry		
- Photoresist	make the photoresist soluble in water and give surface activity	hydrophobic and oleophobic properties
- Photoresist	increase the photosensitivity of the photoresist (photosensitizer)	?
- Photoresist	photo-acid generator	able to generate strong acids
- Antireflective coating	provide low reflectivity	low refractive index
- Developer	facilitate the control of the development process	?
- Etching	wetting agent	low surface tension
- Etching	reduce the reflection of the etching solution	low refractive index
- Etching	etching agent in dry etching	strong acids
- Cleaning of silicon wafers	etch cleaning	strong acids
- Cleaning of integrated circuit modules	remove cured epoxy resins	?
- Cleaning vapour deposition chamber	remove dielectric film build up	generation of reactive oxygen species
- Wafer thinning	non-stick coating composition on carrier wafer	low surface tension
- Vacuum pumps	working fluid	stable, non-reactive
- Technical equipment in contact with process chemical or reactive plasma	polymeric PFAS are used in inert moulds, pipes and elastomers	stable, non-reactive
- Multilayer circuit board	bonding ply composition	low dielectric constant, low dissipation factor
Textile production		
- Dyeing and bleaching of textiles	wetting agent	low surface tension
- Dyeing process using sulphur dyes	antifoaming agent	low surface tension
- Dye transfer material	release agent	low surface tension
- Textile treatment baths	antifoaming agent	low surface tension
- Fibre finishes	emulsifying agent	hydrophobic and oleophobic properties
Watchmaking industry		
- Lubricants	form an oil layer and reduced wear	non-reactive (do not oxidize, resistant to corrosion)

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Drying as production step after aqueous cleaning	solvents in solvent displacement drying	low surface tension
Wood industry		
- Drum filtration during bleaching	the used coarse fabric is made out of polymeric PFAS	stable
- Coating for wood substrate	clear coating is made out of polymeric PFAS	stable, non-reactive
- Wood particleboard	part of adhesive resin	low surface tension
<u>Other use areas</u>		
Aerosol propellant	aerosol propellant	non-flammable, stable, non-reactive
Air conditioning	working fluid	non-flammable, stable, non-reactive
Antifoaming agent	prevent foaming	low surface tension
Ammunition	make the final product rubbery and reduce the likelihood of an unplanned explosion due to shock; enable long-term storage without degradation of the polymer	long-term stability without degradation
Apparel		
- Breathable membranes	polymeric PFAS are used as membranes	high permeability to water vapour, but resist passage of liquid water
- Long-lasting durable water repellent finish	provide water and oil repellence, stain resistance and soil release	lower surface tension of the fabric, hydrophobic and oleophobic properties
Automotive		
- Car body	weather resistance paint, no-wax brilliant top coat	low surface tension
- Automotive waxes	aid spreading, improve the resistance of the polish to water and oil	lower the surface tension of the wax, oleophobic
- Windshield wiper fluid	prevent icing of the wind shield	?
- Car body	light, stable	beneficial weight-to-surface ratio, stable
- Engine and steering system	polymeric PFAS are used as sealants and bearings	operate at a wide temperature range, non-reactive
- Engine oil coolers	heat transfer fluid	good heat conductivity
- Cylinder head coatings and hoses	increase the fuel efficiency	?
- Cylinder head coatings and hoses	reduce the fugitive gasoline vapour emissions	low surface tension
- Electronics	cables and wires	high-temperature endurance, fire resistance
- Fuel lines, steel hydraulic brake tubes	corrosion protection	non-reactive, stable
- Interior	dirt repellent in carpets and seats	low surface tension, oleophobic
- Brake pad additives	?	?
Cleaning compositions		

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Cleaning compositions for hard surfaces	enhance wettability	lower the surface tension of the cleaning product
- Carpet and upholstery cleaners	provide stain resistance and repel soil	low surface tension, oleophobic
- Cleaning compositions for adhesives	?	?
- Dry cleaning fluids	stabilizer, improve the removal of hydrophilic soil	hydrophobic and oleophobic, low surface tension
- Cleaning of reverse osmosis membranes	remove calcium sulphate	?
Coatings, paints and varnishes		
- Paints	emulsifier for the binder, dispersant for the pigments, wetting agent	hydrophobic and oleophobic, low surface tension
- Paints	enhance the protective properties of anticorrosive paints	non-reactive
- Paints	antifouling on ships	?
- Paints and coatings	anti-crater, improved surface appearance, better flow and levelling, reduced foaming, decreased block, open-time extension, oil repellency, dirt pickup resistance	low surface tension, oleophobic
- Paints and coatings	form second coat on a first coat	low surface tension
- Coatings	antistick and anticorrosive coatings	low surface tension, non-reactive
- Coatings	highly durable and weatherable	stable, non-reactive
- Coatings	for food contact materials	hydrophobic and oleophobic, low surface tension
Conservation of books and manuscripts		
	preserve historical manuscripts	permeability to water vapour, but resist passage of liquid water
Cookware		
	prevent food from sticking to the pan	low surface tension, non-reactive, stable at high temperatures
Dispersions		
	disperse solutions	low surface tension
Electronical devices		
- Printed circuit boards	use fibre-reinforced fluoropolymer layer	low dielectric constant
- Liquid impregnates for capacitors	impregnation	high dielectric breakdown strength
- Acoustical equipment	provide an electrical signal in response to mechanical or thermal signals	piezoelectric and pyroelectric properties
- Liquid crystal displays (LCDs)	provide the liquid crystal with a dipole moment	dipoles
- Liquid crystal displays (LCDs)	polymeric PFAS provide moisture sensitive coating for displays	hydrophobic
- Light management films in flat panel display	reduced static electricity build-up and dust attraction during fabrication	low dielectric constant
- Razors	polymeric PFFAs is used on the razor	?
- Electroluminescent lamps	polymeric PFAS is used as coating	?
Fingerprint development		
	solvent	?

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
Fire-fighting foam		
- Fluoroprotein (FP) foams	fuel repellents	low surface tension
- Film-forming fluoroprotein (FFFP) foam	film formers, foam stabilizers	lower the surface tension of water
- Alcohol-resistant film forming fluoroprotein (AR-FFFP) foam	film formers, foam stabilizers	lower the surface tension of water
- Aqueous film-forming foams (AFFF)	film formers	lower the surface tension of water
- Alcohol-resistant aqueous film forming foam (AR-AFFF)	foam stabilizers	low surface tension
Flame retardants		
- Polycarbonate resin	flame retardants	non-flammable
- Other plastic	flame retardants	non-flammable
Floor covering including carpets and floor polish		
	improve wetting and levelling	low surface tension
- Soil-release finishes for carpets	provide water and oil repellence, stain resistance and soil release	low surface tension, hydrophobic and oleophobic
- Aftermarket carpet protection	provide water and oil repellence, stain resistance and soil release	low surface tension, hydrophobic and oleophobic
- Resilient linoleum	?	?
- Laminated floor covering	?	?
- Floor polish	improve levelling and wetting	low surface tension
Glass		
- Surface treatment	make glass surfaces hydrophobic and oleophobic	hydrophobic and oleophobic
- Surface treatment	prevents misting of glass	hydrophobic
- Surface treatment	dirt-repellent	low surface tension
- Surface treatment	fire-or weather resistant	non-flammable, stable
- Etching and polishing	increase the speed of etching, improve wetting	low surface tension
- Drying as production step in glass finishing	solvents in solvent displacement drying	low surface tension
Household applications		
- Threads and joints	polymeric PFAS is used for sealing	?
Laboratory supplies, equipment and instrumentation		
- Consumable materials (vials, caps, tape)	made out of polymeric PFAS	?
- Personal protective equipment (gloves)	?	?
- Particle filters	minimize the sorption of compounds to the filter itself	low surface tension
- Solvents	dissolve other substances	hydrophobic and oleophobic
- LC instruments	polymeric PFAS are used in the solvent degasser	non-reactive ?

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- LC columns	some columns are based on polymeric PFAS	?
- Reverse phase LC-solvents	can contain PFAS	?
- Seals and membranes in UPLCs, autoclaves and ovens	are made out of polymeric PFAS	work over a wide temperature range
- Oils and greases in pumps	form a thick oil layer and reduced wear	non-reactive, non-flammable
- Sterilization of an insulated vessel	sterilization medium	?
- Electrophotting	protein-sequencing membranes are made out of polymeric PFAS	?
- Analysing the phosphoamino content in proteins	protein-sequencing membranes are made out of polymeric PFAS	?
Leather		
- Manufacturing of genuine leather	improve the efficiency of hydrating, pickling, degreasing and tanning	?
- Repellent treatment (genuine leather)	provide water and oil repellence, stain resistance and soil release	hydrophobic and oleophobic , low surface tension
- Manufacturing of synthetic leather	polymer melt additives that impart oil and water repellency to the finished fibres	hydrophobic and oleophobic
- Shoe brighteners	improve the levelling of shoe brighteners	low surface tension
- Impregnation spray	provide water and oil repellence, stain resistance and soil release	low surface tension
Lubricants and Greases	form a thick oil layer and reduced wear	non-reactive, non-flammable, operate also at high temperatures, do not form sludge or varnish
Medical utensils		
- Electronic devices that rely on high frequency signals (defibrillators, pacemakers, cardiac resynchronization therapy (CRT), positron-emission tomography (PET) and magnetic resonance imaging (MRI) devices)	high dielectric insulators	high dielectric breakdown strength
- Video endoscope	use in charge-coupled device colour filters	?
- Microbubble-based ultrasound contrast agents	fluorinated gas inner core, which provides osmotic stabilization and contributes to interfacial tension reduction	low solubility in aqueous media (dissolve more slowly)
- X-ray imaging	contrast enhancement agents	radio-opaque
- Magnetic resonance imaging	contrast agent	lack of a ¹⁹ F endogenous background signal in vivo and high magnetic resonance sensitivity of ¹⁹ F atoms
- Proton and ¹⁹ F NMR imaging	contrast agents	lack of fluorine in organs and tissue
- Computed tomography and sonography	contrast agents	lack of fluorine in organs and tissue
- Radio-opaque materials	polymeric PFAS has been used	radio-opaque
- Surgical drapes and gowns	improve water-, oil- and dirt-resistance	hydrophobic and oleophobic, low surface tension

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- X-Ray films	wetting agents, emulsion additives, stabilizers and antistatic agent	low surface tension, low dielectric constant
- Dispersant	facilitate the dispersion of cell aggregates	low surface tension
- Contact Lenses	raw material	
- Retinal detachment surgery and proliferative vitreoret.	endotamponade gases	high specific gravity, low surface tension, and low viscosity
- Retinal detachment surgery and proliferative vitreoret.	intraoperative tool during vitreoretinal surgery	high specific gravity, low surface tension, and low viscosity
- Eye drops	delivery agent	unique combination of apolarity and amphiphility
- Filters, tubing, O-rings, seals and gaskets in dialysis machines	made out of polymeric PFAS	low surface tension
- Dialysis membranes	made out of polymeric PFAS	low surface tension
- Catheter, stents, and needles	provide low-friction and clot-resistant coatings	low surface tension
- Surgical patches and vascular catheter	use of polymeric PFAS	?
- Blood transfer and artificial blood	oxygen carrier	great capacity to dissolve gases
- Organ perfusion	oxygen carrier	great capacity to dissolve gases
- Percutaneous transluminal coronary angioplasty	oxygen carrier	great capacity to dissolve gases
- Toothpaste	enhances fluorapatite formation and inhibits caries	low surface tension
- Dental floss	allows the narrow ribbon to slip easily between close-pressed teeth	low surface tension
- UV-hardened dental restorative materials	improve the wetting of the set materials	low surface tension
- Ventilation of respiratory airway	?	?
- Anaesthesia	polymeric PFAS is used to dry or humidify breath	hydrophobic
- Artificial heart pump	blood compatible and durable	non-reactive, stable
- Wound care	cleaning burn residues	dissolve hydrocarbon
Metallic and ceramic surfaces	generates easily removable sludge	hydrophobic and oleophobic
Music instruments		
- Guitar strings	prevent loss of vibration due to residue build up	?
- Piano keys	contain polymeric PFAS	?
- Piano	eliminate squeaks in piano key	?
Optical devices		
- Glass fibre optics	able to include rare earth in glass fibre optics	?
- Optical lenses	provide optical lenses with low refractive index and high transparency	low refractive index
Paper and packaging		
- Paper and cardboard	provide water- and oil repellency	hydrophobic and oleophobic

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Manufacturing of paper	release agent for paper-coating compositions	low surface tension
Particle physics		
- Particle accelerators	part of the detection assemblies	non-reactive, stable ?
Personal care products		
- Cosmetics	emulsifiers, lubricants, or oleophobic agents	hydrophobic, low surface tension
- Cosmetics	make creams etc. penetrate the skin more easily	
- Cosmetics	make the skin brighter	
- Cosmetics	make the skin absorb more oxygen	great capacity to dissolve gases
- Cosmetics	make the makeup more durable and weather resistant	hydrophobic and oleophobic, stable, non-reactive
- Hair-conditioning formulations	enhance wet combing and render hair oleophobic	
Pesticides		
- Insecticide against the common housefly and carmite mite	suffocation of the insect by the adsorbed fluorinated surfactant	?
- Insecticide against ants and cockroaches	?	?
- Formulation additives	anti-foaming agent	low surface tension
- Formulation additives	dispersant, facilitate the spreading of plant protection agents on insects and plant leaves	low surface tension
- Formulation additives	dispersant, increase uptake by insects and plants	low surface tension
- Formulation additive	wetting agent for leaves	low surface tension
Pharmaceuticals		
- Active ingredient (Fulvestrant)	estrogen antagonists, inhibits the growth stimulus that the estrogen exert on cells	?
- Active ingredient	pharmaceutical combination of dabigatran and proton pump inhibitors	?
- Formulation additives	dispersant in self-propelling aerosol pharmaceuticals	low surface tension
- Formulation additives	solvent	hydrophobic and oleophobic
Pipes, pumps, fittings and liners		
- Pipes, pipe plugs, seal glands, pump parts, fasteners, fittings and liners	polymeric PFAS are used for these applications	stable, non-reactive, low surface tension, hydrophobic and oleophobic
- Working fluid for pumps in the electronics industry	stable to reactive gases and aluminium chloride	extremely stable, non-reactive
Plastic and rubber		
- Plastic	polymeric PFAS micropowder as additive ?	?
- Thermoplastic	plasticizer	?

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- ABS laminates	contain polymeric PFAS for improved weather resistance	non-reactive, stable
- Bonding of rubber to steel	allow adhesiveless bonding	low surface tension
- Rubber and plastic	antistatic agent	low dielectric constant
Printing (inks)		
- Toner and printer ink	enhance ink flow and levelling, improve wetting, aid pigment dispersion	low surface tension
- Toner and printer ink	impart water resistance to water-based inks	hydrophobic
- Ink-jet recording heads	make them ink repellent	low surface tension
- Recording and printing paper	?	?
- Lithographic printing plates	?	?
Refrigerant systems		
- Refrigerant fluid system	heat transfer fluid	good heat conductivity
- Refrigerant compressor	lubricants	non-flammable
Resins		
- Resin	improve weatherability and elasticity	non-reactive, stable
- Resin for coating of glass, aluminium or mild steel	water- and oil repellent	hydrophobic and oleophobic
- Polycarbonate resins	flame retardant for polycarbonate resins	non-flammable
- Composite resins	improve wetting of fibres or fillers	low surface tension
- Composite resins	speed the escape of bubbles trapped in the viscous resin	low surface tension
Sealants and adhesives		
- Sealants	can be made out of polymeric PFAS	operate at a wide temperature range, non-reactive, stable
- Silicone rubber seals	prevents soiling	low surface tension, hydrophobic and oleophobic
- Adhesives	improve levelling, spreading, and the penetration of the adhesive into the pore structure of the substrates	low surface tension
- Adhesives	antistatic agent	low dielectric constant
Soldering		
- Vapour phase fluids in vapour phase soldering	heat transfer medium	good heat conductivity
- Fluxing agent in solder paste	low-foaming noncorrosive wetting agent	non-reactive, stable, low surface tension
Soil remediation		
- Vapour barrier material on top of contaminated soil	evaporation retarder	?
- Surfactants to mobilize pollutants	surfactants to mobilize soil-bound contaminants in remediation	stable, non-degradable (during photodegradation)
Sport article		

Use category/subcategory	Function of PFAS	Properties of the PFAS employed
- Ski wax	highly water repellent	low surface tension, hydrophobic
- (Sailing) boat equipment	weather protection of textiles; anti-fouling protection of ship hulls	non-reactive, stable, hydrophobic and oleophobic
- Tennis rackets	used in coatings for tennis rackets	?
- Bicycle	lubricants	hydrophobic
- Climbing ropes	provide water repellence, stain resistance and soil release	low surface tension, hydrophobic
- Fishing lines	no water absorption, invisible in water, high knot strength	hydrophobic
Stone, concrete and tile	impart oil and water repellency to the surface; delay oxidation and ageing of surface	low surface tension, hydrophobic and oleophobic
Textile and upholstery		
- Surface treatment	provide water and oil repellence, stain resistance and soil release	low surface tension, hydrophobic and oleophobic
- Waving yarn	facilitate waving	?
Tracing and tagging		
- Tracking air-borne pollutants	tracer in air	non-radioactive, chemically and thermally stable, do not occur naturally, have very low atmospheric background concentrations
- Testing ventilation systems	tracer in air	“
- Mapping gas and petroleum reservoirs	tracer in gas or petroleum	“
- Leak detection in cables, pipelines, landfill waste and underground storage tanks	tracer in leaking material	“
- Tracking of marked items	tracer in the marked item	“
Water and effluent treatment		
- Filter membranes	polymeric PFAS minimize the sorption of compounds to the filter itself	low surface tension
Wire and Cable	provide high-temperature endurance, fire resistance, and high-stress crack resistance	non-flammable, operate at a wide temperature range

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2**Environmental Significance Statement**

Per- and polyfluoroalkyl substances (PFAS) are a large group of more than 4000 substances that are used in a wide range of technical applications and consumer products. Releases of PFAS to the environment have caused large-scale contamination in many countries. For an effective management of PFAS, an overview of the use areas of PFAS, the functions of PFAS in these uses, and the chemical identity of the PFAS actually used is needed. Here we present a systematic description of more than 200 uses of PFAS and the individual substances associated with each of them (over 1400 PFAS in total). This large list of PFAS and their uses is intended to support the identification of essential and non-essential uses of PFAS.

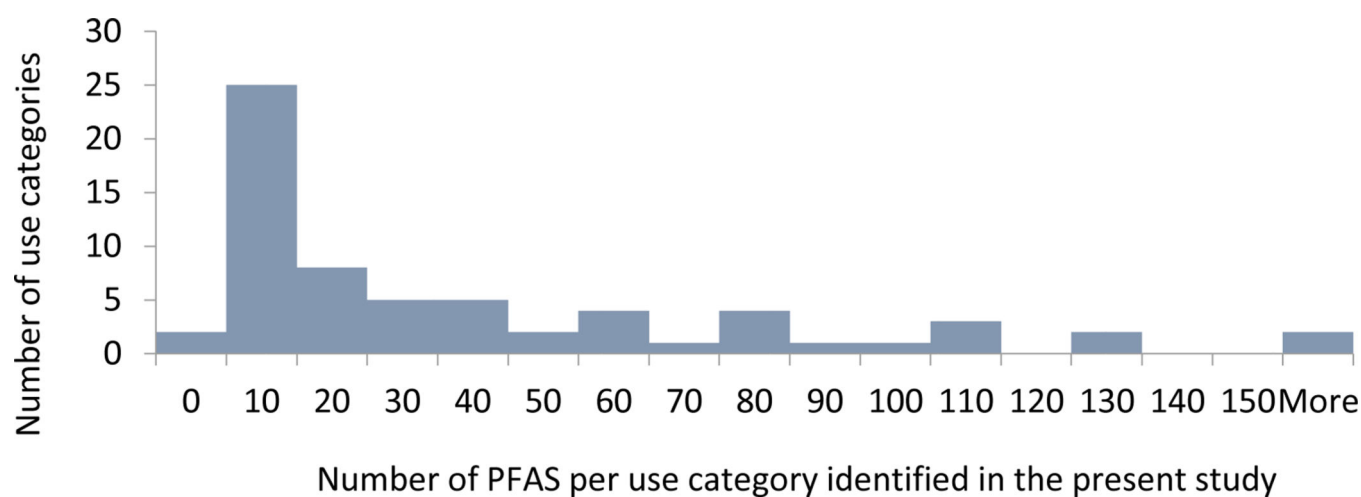


Figure 1:

Use categories grouped according to the number of PFAS identified. The use categories are those mentioned in Table 1 without distinction of subcategories. Identified PFAS included PFAS detected analytically in products, patented and employed PFAS.

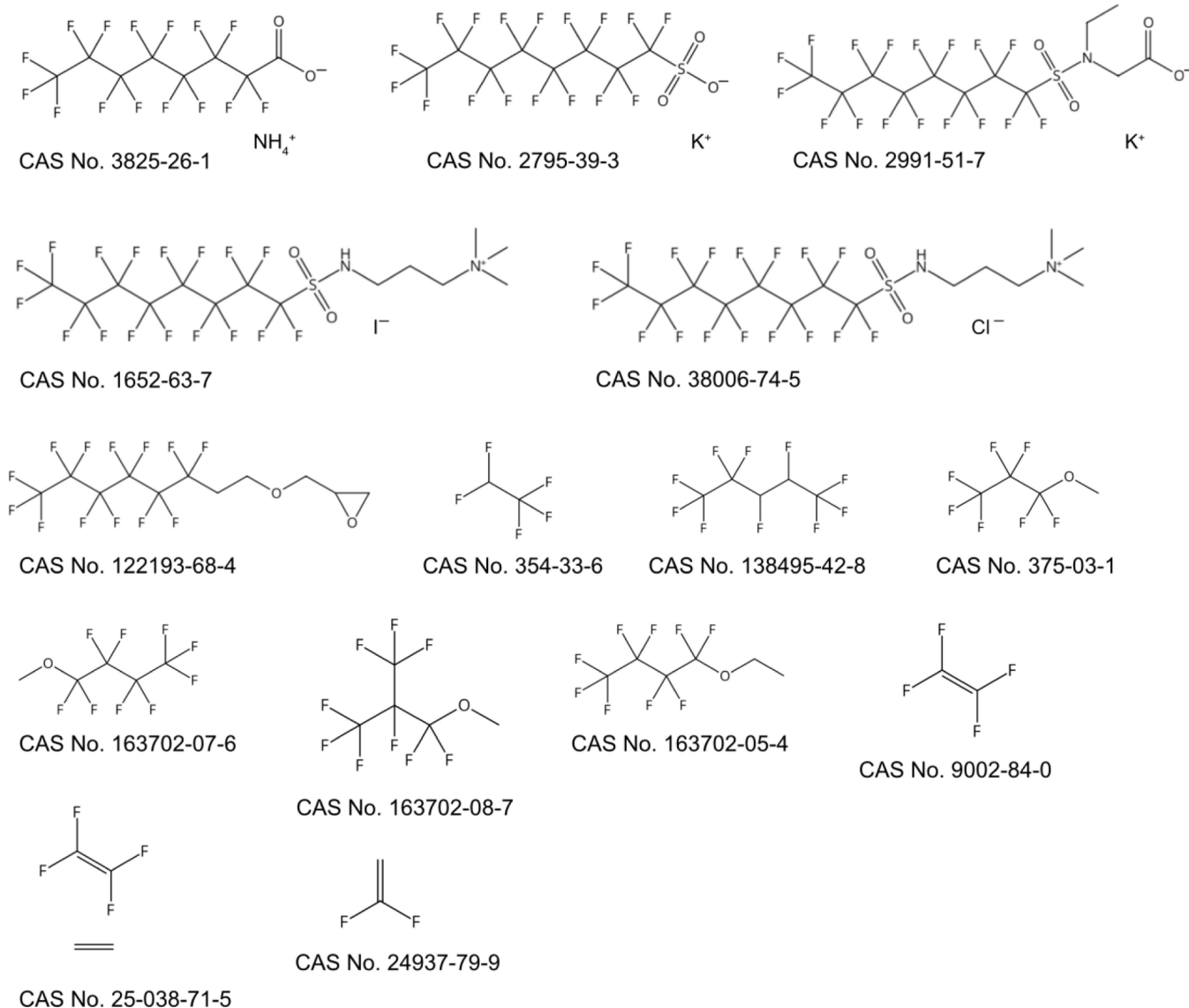


Figure 2:
Structures and CAS numbers of the PFAS with more than 10 assigned uses.

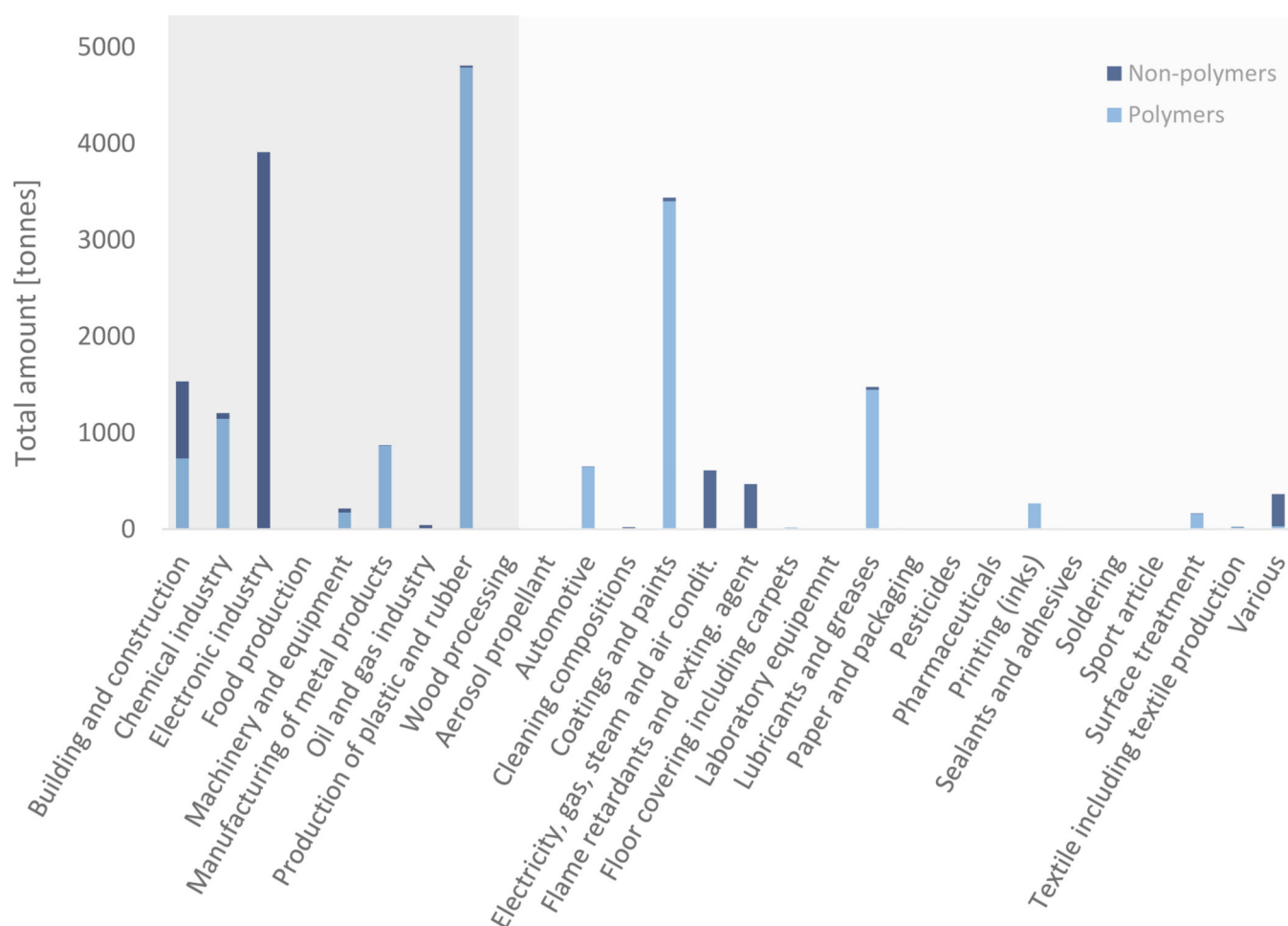


Figure 3:

Amount of PFAS employed in the different use categories in Sweden, Finland, Norway and Denmark from 2000 to 2017, as reported in the SPIN database.⁴¹ Polymers include fluoropolymers and perfluoropolyethers. Side-chain fluorinated polymers have not been used above 0.2 t in any of the uses. Use categories with dark background are industrial branches, use categories with light grey background are other use categories.

Table 1:

Industry branches and other use categories where PFAS were or are employed. The numbers in parentheses indicate the number of subcategories. No parentheses indicate no subcategories.

<u>Industry branches</u>	
Aerospace (7)	Mining (3)
Biotechnology (2)	Nuclear industry
Building and construction (5)	Oil & gas industry (7)
Chemical industry (8)	Pharmaceutical industry
Electroplating (2)	Photographic industry (2)
Electronic industry (6)	Production of plastic and rubber (5)
Energy sector (10)	Semiconductor industry (11)
Food production industry	Textile production (2)
Machinery and equipment	Watchmaking industry
Manufacture of metal products (7)	Wood industry (3)
<u>Other use categories</u>	
Aerosol propellants	Metallic and ceramic surfaces
Air conditioning	Music instruments (3)
Antifoaming agent	Optical devices (3)
Ammunition	Paper and packaging (2)
Apparel	Particle physics
Automotive (12)	Personal care products
Cleaning compositions (6)	Pesticides (2)
Coatings, paints and varnishes (3)	Pharmaceuticals (2)
Conservation of books and manuscripts	Pipes, pumps, fittings and liners
Cookware	Plastic and rubber (3)
Dispersions	Printing (4)
Electronic devices (7)	Refrigerant systems
Fingerprint development	Resins (3)
Fire-fighting foam (5)	Sealants and adhesives (2)
Flame retardants	Soldering (2)
Floor covering including carpets and floor polish (4)	Soil remediation
Glass (3)	Sport article (6)
Household applications	Stone, concrete and tile
Laboratory supplies, equipment and instrumentation (4)	Textile and upholstery (2)
Leather (4)	Tracing and tagging (5)
Lubricants and greases (2)	Water and effluent treatment
Medical utensils (14)	Wire and cable insulation, gaskets and hoses

Table 2:

PFAS with more than 10 assigned uses. Numbers based on counts of uses and patents, not on detections in products. The structures of these substances are shown in Figure 2.

Substance	CAS number	Assigned uses
Ammonium perfluorooctanoate	3825-26-1	14
Potassium perfluorooctane sulfonate	2795-39-3	16
Potassium <i>N</i> -ethyl perfluorooctane sulfonamidoacetate	2991-51-7	21
1-Propanaminium, 3-[[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptafluorooctyl)sulfonyl]amino]- <i>N,N,N</i> -trimethyl-, iodide (1:1)	1652-63-7	17
1-Propanaminium, 3-[[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,9-heptafluorooctyl)sulfonyl]amino]- <i>N,N,N</i> -trimethyl-, chloride	38006-74-5	21
Oxirane, 2-[[[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)oxy]methyl]-	122193-68-4	11
1H-Pentafluoroethane	354-33-6	10
Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-	138495-42-8	12
Methyl perfluoropropyl ether	375-03-1	13
Methyl perfluorobutyl ether	163702-07-6	16
Methyl perfluoroisobutyl ether	163702-08-7	16
Ethyl perfluorobutyl ether	163702-05-4	12
Polytetrafluoroethylene (PTFE)	9002-84-0	37
Poly(vinylidene fluoride) (PVDF)	24937-79-9	17
Ethylene tetrafluoroethylene copolymer (ETFE)	25038-71-5	10

Table 3:

Amounts (used + exported) that were not labelled as CBI for the different uses of PFAS from the Chemical Data Reporting under the TSCA from 2016. The rows with grey background are the uses with high amounts indicated by non-confidential data.

Sector and function	Amount [t]
Paint and coating manufacturing - Adhesive and sealant chemicals	0.001
Industrial gas manufacturing - Air conditioner/refrigeration	138
Computer and electronic product manufacturing - Solvent for cleaning and degreasing	1.03
Electrical equipment, appliance, and component manufacturing - Functional fluid	2180
Fabricated metal product manufacturing - Solvent for cleaning and degreasing	0.11
All other chemical product and preparation manufacturing - Fire-fighting foam agents	190
Machinery manufacturing - Functional fluid	2180
Miscellaneous manufacturing - Solvent for cleaning and degreasing	0.10
Oil and gas drilling - Surface active agent	0.022
Paint and coating manufacturing - Adhesives and sealant chemicals	0.31
Paint and coating manufacturing - Finishing agent	0.005
Paper manufacturing - Finishing agent	0.005
Pesticide, fertilizer, and other agricultural chemical manufacturing - Surface active agents	0.07
Miscellaneous manufacturing - Plating agent and surface treating	1.96
Printing ink manufacturing - Processing aids, not otherwise listed	0.001
All other basic inorganic chemical manufacturing - Refrigerant (heat transfer fluid)	450
Rubber product manufacturing - Rubber compounding	0.13
Soap, cleaning compound, and toilet preparation manufacturing - Surface active agents	0.12
Textile, apparel and leather manufacturing - Finishing agents	0.16

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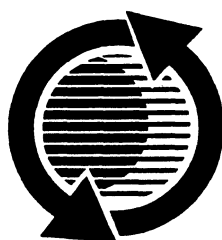
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Fuel Hose Permeation of Fluoropolymers

D. Roy Goldsberry

E.I. Du Pont de Nemours & Co., Inc.

ABSTRACT

New and proposed air emissions regulations at the state and federal level are continuing to drive automotive engineers to improve fuel systems. These efforts often include the use of oxygenated fuels, and fuel systems which are more resistant to permeation of many fuel types. This study compares the fuel permeabilities of several fluoropolymers and nylon in fuel C, methanol, and blends of 80% fuel C with methanol, MTBE, and ETBE.

The findings of this study include: fuel permeation rates through fluoropolymer hose are very low and much better than through nylon; fluoropolymer hose has low selective permeability to fuel blend components; permeation rates of oxygenated fuel blends through fluoropolymer hose are not significantly different than for fuel C; and electrically conductive additive does not significantly affect the fuel permeability of fluoropolymer hose.

INTRODUCTION

Hydrocarbon emissions requirements for vehicles are continuing to tighten. These emissions include engine exhaust and evaporative losses, such as permeation. Efforts to reduce exhaust emissions include the use of oxygenated fuels, which then requires an understanding of how these fuels permeate. Fluoropolymer fuel hose has been shown to exhibit excellent chemical resistance and very low permeability in current commercial service. The purpose of this paper is to evaluate the permeation performance of several types of fluoropolymer hose in oxygenated fuels and to confirm previous work on the effect of conductive additive on permeation.

TEST METHOD

The test procedure used to measure permeation rates was SAE J-30.6.12. This procedure called for a 38 cm length of sample hose, with one end plugged, to be attached to a small container which served as a fuel reservoir.

To prevent potential corrosion by the fuel blends, the reservoir was made from stainless steel pipe rather than the light metal container specified by J-30. After a known composition of a fuel mixture was added to the reservoir, the entire system was sealed, and placed in a controlled, 23°C environment. Permeation rates were determined by measuring the weight loss from the entire apparatus at timed intervals. Weights were taken to the nearest 0.001g, and the data were collected over a two to three month period.

TEST PARAMETERS

This study was conducted using the following fuels:

Fuel C - 50:50 volume blend of iso-octane and toluene

Methanol - methyl alcohol (M100)

M20 - 20 volume percent methanol in Fuel C

MTBE20 - 20 volume percent methyl tertiary-butyl ether in Fuel C

ETBE20 - 20 volume percent ethyl tertiary-butyl ether in Fuel C

The fuel hose materials used were:

TEFLON® PTFE 62 -polytetrafluoroethylene;
fine powder type; paste extrusion resin.

TEFZEL® ETFE 200 - ethylene tetrafluoroethylene
copolymer; general purpose melt extrusion resin.

TEFLON® PFA 340 - copolymer of
tetrafluoroethylene and a perfluoroalkoxy
monomer; general purpose melt extrusion resin.

Nylon 12 - polyamide; plasticized melt extrusion
resin.

ETFE hose was also tested with a conductive
carbon additive; PTFE hose was also tested with an
inner liner containing a conductive carbon additive.

For each combination of hose and fuel (not all
combinations were tested), four test cell replicates were
prepared. The weight loss data for each replicate was
plotted versus time, and the permeation rate was
calculated from the equilibrium period for those
replicates showing reasonable agreement. High outliers
were assumed to be leaking and were not included in
the calculation.

Other permeation studies have sometimes reported
peak permeation rates, which are often seen in the first
few days of the test, but can come as late as one to two
weeks into the test. There is evidence which suggests
that these peak rates are not relevant to fuel hose and
only equilibrium rates need be considered.

Permeation is a function of the solubility of the
permeant in the polymer and the diffusion of the
permeant through the polymer. Diffusion is a function
of concentration, and the diffusion coefficient can vary
with concentration as well. In the early stages of a
permeation test, the polymer is changing from zero
permeant concentration to some saturated or maximum
level, and this implies a variable permeation rate during
this period due to the impact of varying concentrations
on diffusion. As the permeant concentration
equilibrates, so too should the permeation rate, if other
factors are constant. Since the fuel hose on a vehicle is
filled with fuel virtually all of the time, only the
equilibrium concentration is relevant, and so too only
equilibrium permeation rates are relevant.

The data were normalized to account for any
sample variation in length, inside diameter, or wall
thickness. These results are shown in Table 1 and are
reported as $(g \times mm)/(m^2 \times day)$, where mm represents
the thickness of the hose wall and m^2 represents the
inside surface area of the tube.

Wall thickness for the tested hoses ranged between
.4 mm and 1 mm, and the inside diameter of the hoses
ranged from 6 to 8 mm. To calculate fuel loss in grams
per day, one would multiply the permeation rate from
Table 1 by the inside area of hose in m^2 and divide by
the hose wall thickness in mm.

TABLE 1

PERMEATION RATE
 $(g \times mm)/(m^2 \times day)$

<u>HOSE</u>	<u>FUEL C</u>	<u>M20</u>	<u>M100</u>	<u>MTBE20</u>	<u>ETBE20</u>
PTFE	0.06		0.09		
PTFE cond. lined	0.05	0.08	0.08	0.04	0.05
ETFE	0.02	0.04	0.03	0.01	0.05
ETFE conductive	0.01				
PFA	0.01	0.05	0.05		
Nylon 12	1.53				

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Following completion of the permeation tests, selected test cells were sampled for the residual fuel, and these samples were analyzed by gas chromatograph to determine the final concentration of the fuel components. This was done to look for evidence of selective permeation by the fuel components. These results are shown in Table 2.

RESULTS

EFFECTS OF POLYMER TYPE

The first result of this testing is that the three fluoropolymers demonstrated very low rates of fuel permeation, ranging from 0.01 to 0.09 (g x mm)/(m² x day), with fairly modest differences between each of the three types. The permeation rate for nylon 12 was 1.53 (g x mm)/(m² x day) and was approximately 40 times higher than for the fluoropolymers. This result is also shown in Figure 1. As a comparison, a typical fuel line system (8 mm diameter, 1 mm wall, 10 meters long) made from nylon 12 would lose about 0.4 grams of fuel per day at these rates compared to about 0.01 grams per day for fluoropolymer fuel hose.

Nylon also shows a greater degree of selective permeation. The initial 50:50 mixture of toluene and iso-octane shifted to 45:55 due to a higher permeation rate of toluene through nylon than iso-octane. For the fluoropolymers, this selective permeation was from 2 to 5 times lower, and the original fuel composition was more closely retained than for nylon.

Comparison of permeation rate differences between the three fluoropolymer types is not as clear. Due to

experimental accuracy, the margin of error in the reported permeation rates is at least 0.05 (g x mm)/(m² x day). PTFE seems to be slightly more permeable to the fuels than the other fluoropolymers, but this difference is within the margin of error and may not be meaningful. There was no evidence that conductive additive had any significant impact on permeation rates.

EFFECTS OF FUEL BLEND COMPOSITION

The data show that oxygenated fuel blends containing methanol, MTBE, or ETBE at a 20% concentration, do not permeate through fluoropolymers at a significantly different rate than does fuel C. Even pure methanol did not permeate at a significantly different rate. These results are shown again in Figure 2. The small differences seen in the reported rates are all within the margin of error. Also, the concentration of methanol in M20 did not change over the course of the permeation test (2-3 months).

This result can be better understood if we again consider the functional elements of permeation: diffusivity and solubility. The butyl ethers are slightly smaller in size than the molecules in fuel C. This would suggest slightly higher diffusivity. However, the ethers are moderately polar, and this would make them less soluble in the non-polar polymers being studied than the relatively non-polar fuel C. The impact of this lower solubility makes the ethers equally, if not less, permeable than fuel C through the fluoropolymers tested, and no significant difference was seen for the 20% blends.

TABLE 2
FUEL MIXTURE COMPOSITIONS
Volume Percent

	<u>Before Permeation</u>			<u>After Permeation</u>		
	<u>Toluene</u>	<u>ISO-Octane</u>	<u>Methanol</u>	<u>Toluene</u>	<u>ISO-Octane</u>	<u>Methanol</u>
PTFE cond. lined	50	50	0	49	51	0
PTFE cond. lined	40	40	20	38	42	20
ETFE	50	50	0	49	51	0
ETFE	40	40	20	37	42	21
Nylon	50	50	0	45	55	0

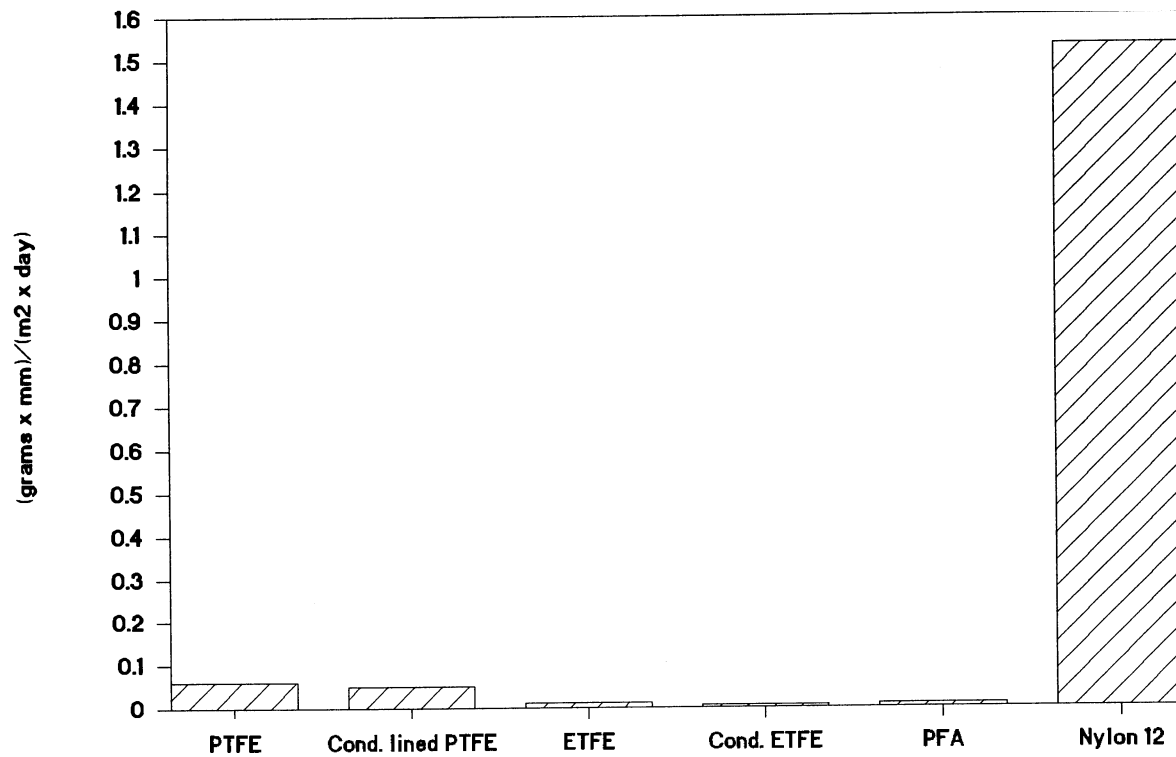


FIGURE 1 - Permeation of Fuel C

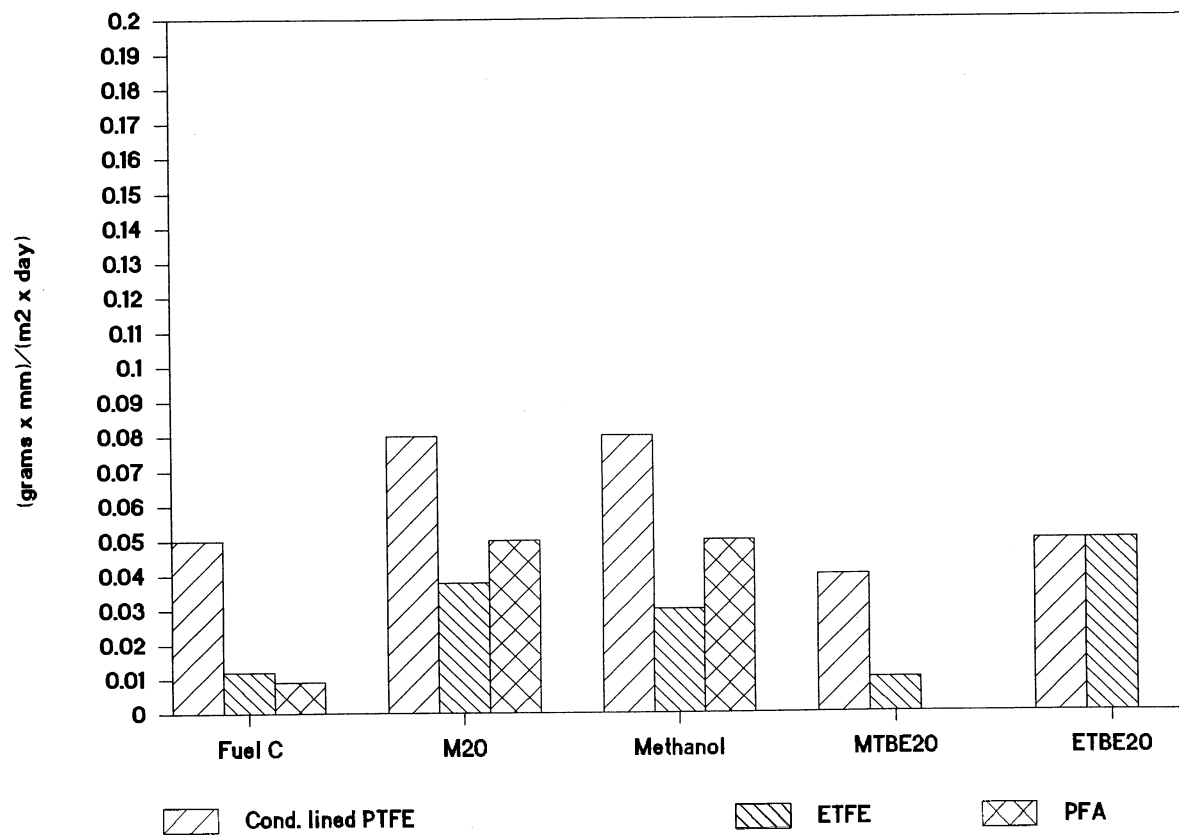


FIGURE 2 - Permeation of Fuel C and Oxygenated Fuels

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For methanol, the impact of the two functional elements of permeation is more extreme, but still opposing, and the end result is similar to that for the ethers. Methanol is much smaller than the fuel C molecules, but it is also even more polar than the ethers. Thus, the permeation rate of methanol through the fluoropolymers is also similar to that for fuel C.

CONCLUSION

The fluoropolymers PTFE, ETFE, and PFA are extremely well suited as fuel hose materials for minimizing hydrocarbon emissions due to permeation. These polymers were shown to exhibit extremely low permeabilities to fuel, on average 40 times lower than nylon. The permeation rate was not affected by typical quantities of conductive additive. The permeabilities of the above fluoropolymers were little changed between fuel C, methanol, and 80/20 blends of fuel C with methanol, ETBE, and MTBE. The different components of these blends also permeated at similar rates.

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