DIGITALEUROPE

European Chemicals Agency consultation:

Per- and polyfluoroalkyl substances (PFAS) restriction proposal

– DIGITALEUROPE use-specific derogation requests –

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Introduction

Shared goal of a safe transition toward PFAS-free electronics

The digital industry has been, and continues to be, committed to improving the environmental performance and safety of all products placed on the market.

DIGITALEUROPE members support moving towards PFAS-free electronics and are actively investigating the uses of PFAS and the availability of alternatives in an effort to substitute PFAS wherever possible in a timely fashion.

It will however take time for the digital and electronics industries to replace PFAS in their products and processes in a safe, responsible manner. There are considerable challenges related to full implementation of PFAS substitution plans in this sector, such as accurately cataloguing PFAS uses across thousands of component articles, identifying and developing non-PFAS alternatives that can meet the safety and performance needs for each application, and the time needed for material qualification, component and full product re-design, testing and certification. In many cases, there are currently no technically viable alternatives known, and they will need to be developed, qualified and made commercially available.

DIGITALEUROPE contributions to the public consultation

In our first contribution[1] to this public consultation, DIGITALEUROPE has highlighted the need for derogations for:

- **Spare parts for repair of finished consumer electronic equipment already placed on the market,**
- **Spare parts for repair of finished professional business-to-business electronic equipment already placed on the market,**
- **Re-supply of articles already placed on the market (pre-owned products)**

In our second contribution[2] DIGITALEUROPE has explained the need for a **general five-year derogation for electronics (in addition to the generally applicable 18-month transition period called for in the proposal)** for electronics suppliers and manufacturers to gather complete, accurate data and to complete the redesign, testing, certification, and production.

For a number of uses of PFAS in electronics, very specific information is already available on why PFAS is used, which substances are used and the feasibility of several alternatives. In the current document an overview is presented of those specific uses for which, in our view, time-limited derogations are required.

Depending on the availability of alternatives and their maturity, a longer (13.5-year) or shorter (6.5-year) derogation is requested. For several uses we request a 6.5-year derogation (5 years on top of the 18-month transition period), these derogations will not be needed if a general 6.5-year derogation is granted for all electronic equipment (as requested in our second contribution).

[1] RCOM 5927, submitted on 28 June 2023
[2] Submitted concurrently with this document

Detailed information is provided to allow the ECHA scientific committees to evaluate these derogation requests. If for any reason more information is needed, we invite the committees to contact us.

Contributions from other sector associations

As also highlighted in our previous contribution to the public consultation, although the total amount (annual tonnage) of PFAS in electronics is very small, the number of different uses is very large. The current document does not intend to provide a complete overview of all derogations that are required in order to secure the availability of electronic devices. Electronic devices contain many components that can have long supply chains. PFAS can be required by other actors in the supply chain. If these uses are critical for their applications, they are also critical for the entire electronics industry. For example, the entire electronics sector depends fundamentally on the availability of cutting-edge semiconductor technology. The semiconductor manufacturing sector generally sits upstream in DIGITALEUROPE members' supply chains. Our understanding is that PFAS uses are irreplaceable for a number of semiconductor manufacturing-related applications, and that PFAS may be used in (or residues found on) semiconductors as well. We therefore strongly support the detailed assessments and derogation substantiations that we understand will be submitted to ECHA by our partners in the semiconductor value chain[3]. Other sector associations have also submitted derogation requests for other uses. We want to emphasize the need to also provide these derogations.

Impact of the restriction proposal and proportionality

Economic study

If the universal PFAS restriction as proposed by the dossier submitters in the Annex XV report would enter into force unchanged, the impact on the electronics industry would be devastating. There are many uses of PFAS in electronics and as REACH requires each individual article in a complex product to comply, the entire product cannot be sold if only one single element of PFAS cannot be replaced in the product.

A recent study by Ricardo Energy & Environment, commissioned by the European Chemical Industry Council (Cefic), estimated the final economic impact of the PFAS restriction on various sectors.[4] A significant number of DIGITALEUROPE members contributed data to the study. The results clearly demonstrate that the PFAS restriction, should it enter into force in its currently proposed form, would have a devastating impact on the economic performance of the electronics industry in Europe. The annual overall turnover losses for computers, small and large printers, electronic and optical products are estimated at 78% against a 2021 baseline. For electronic components, an 84% turnover loss is estimated.[5] This strongly underlines the need for the derogations requested by DIGITALEUROPE in our contributions.

[3] See semiconductor PFAS Consortium of the Semiconductor Industry Association, https://www.semiconductors.org/pfas/.
[4] Ricardo Energy & Environment (2023): Economic analysis of the impacts of a REACH restriction on the manufacture, placing on the market and use of per- and polyfluoroalkyl substances, Report for The European Chemicals Industry Council (Cefic). See Cefic contribution to this public consultation
[5] ibid p. 57-58

Emissions

According to the Annex XV report the emissions to the environment from electronics are less than 1% of all PFAS emissions. Most uses in electronics concern fluoropolymers. Since fluoropolymers do not evaporate, are not water-soluble and are solid, the emission during the use-phase is negligible. Most fluoropolymers are not classified as hazardous according to the EU CLP regulation.

Not granting the derogations that are required to manufacture and sell electronic products would be disproportionate to the low risk of emissions for the environment.

Overview of DIGITALEUROPE use-specific derogation requests

Table 1 presents an overview of all use-specific derogation requests covered in this submission.

Table 1 Overview of DIGITALEUROPE derogation requests

Requested derogation	Requested derogation duration (in addition to the 18-month transition period)
Printer-related uses	
Printheads	12 years
Sealing materials, valves and pumps in inkjet printers	12 years
Factories for ink and printer components	12 years
Electrophotographic printers	12 years
Paper guiding parts	Until 2035
PFAS material in Lithium-ion batteries	
Cathode binder material for Lithium-ion battery cells	12 years
Separator binder materials in Lithium-ion battery cells	5 years
Coating materials	
Anti-fingerprint coating	5 years
Coating and paint for enhanced abrasion resistance in EEE	5 years
Coating in connectors	5 years
Optical isolation layers for display applications	5 years
Anti-dripping agents	12 years
Cables/Connectors	12 years
Capacitors	12 years
Grease & Lubricants	
Grease/lubricants on mechanical parts in EEE	12 years
Lubricant in connectors	12 years
Cooling in data centres	Unlimited
Mechanical Applications	5 years
Ingress Protection Vents for Communication Devices	12 years
Mobile Telecommunication network infrastructure equipment	12 years

1. Printer related uses

In printing equipment and in the manufacturing of inks and toners, PFAS can currently not be replaced in the following applications:

- Print heads
- Sealing materials, valves and pumps in inkjet printers
- Factories for ink and printer components
- Electrophotographic printers
- Paper guiding parts

1.1 Printheads

General summary of the application category

The parts of the nozzle plate of the printhead used in inkjet printers and printing presses produce printed materials at high speed and quality, providing users with printed materials that can be used for documents, photographs, and commercial applications. Taking advantage of the features of digital printing, it contributes to shortening the delivery time and reducing waste such as trial printing, and it continues to develop while mutually complementing conventional analogue printing.

Inkjet printers use PFAS in the parts of the printhead's nozzle plate for ejecting ink for the purpose of developing functions described below.

With the current technology, there is no substitute that can maintain the same quality as PFAS. If PFAS materials cannot be used, a complete redesign of the printing process in the printer is required since the functionality of the printhead is at the heart of the printer. But even after a redesign, the quality of the product will be much worse than current. As a result, there is a risk that the product life will shorten and the environmental impact will increase due to the increase of waste.

There is no substitute at present, so new material development will be necessary, and if the quality equivalent to PFAS cannot be achieved, not only the print head material may need to be changed, but also the unit configuration of the printer body and the control mechanism may need to be redesigned. Because of the required development of new materials and printers including a long-term evaluation, a sufficient exemption period (approximately 12 years) must be set.

The key functionalities provided by PFAS for the relevant use

To provide such an objective at a low cost and with a simple mechanism, PFAS is used in the parts of the print head nozzle plate.

In particular, technological advances in the latest print heads include a decrease in the volume of ink droplets. This serves two purposes. One is to reduce the graininess of the image, which stands out when the droplet size is large. In order to produce high-quality images as required for photography and commercial applications, low graininess is required.

The second purpose is to minimize user costs and the environmental impact of operating inkjet printers. The use of ink can be significantly reduced by efficiently coating the recording media

with small ink droplets in high density. This can help reduce the cost of using ink and the CO_2 emissions associated with transportation. And while commercial high-speed printing machines require drying of the ink by evaporation of moisture, the energy required for drying can be significantly reduced to minimize environmental impacts by lowering the droplet volume.

In order to form a print with a minimum amount of ink and with good image quality, the ink needs to land precisely on the medium at a defined location. To make such small droplets of ink to fly stably, it is important that the surface of the nozzle plate is clean and that the nozzle plate does not deform (swell) over a long period of use.

If the surface of the nozzle plate is contaminated, for example, by ink sticking to it, there is a risk that the flight will be bent when ink is ejected from the nozzle plate or that no ink will be jetted at all from that nozzle. Also, even if the nozzle plate swells, the flight angle may change. This results in a bad image quality.

Especially in recent years, the volume of droplets has become smaller. Very small ink droplets are susceptible to contamination of the nozzle plate surface, and the surface must be kept extremely stable.

For this reason, water repellent PFAS materials are used as nozzle plate surface coating to prevent contamination of the nozzle plate surface. PFAS material in the nozzle plate is applied to prevent deformation (swelling) of the nozzles that form the ink channel. Without the use of PFAS materials it is not possible to make the small droplets fly stably in the right direction.

Critical requirements of the nozzle plate coating are- (1) low surface energy & low ink adhesion enables ink to not wet, easy to clean off, no residue left by jetted drop, maintain drool pressure, (2) chemical inertness towards ink, (3) high temp & pressure stability to enable adhesive bonding steps (~ 24 bar, 270 oC) during PH fabrication, (4) ability to be drilled cleanly by lasers yielding crisp & well defined nozzle edges, & (5) Manufacturable (coating on nozzle plate substrate) with tight tolerances.

Information on (lack of) alternatives and supporting arguments

Detailed information on the lack of alternatives can be found in the confidential appendix. It can be concluded that there are no viable alternatives to the use of PFAS for water repellence of the printhead nozzle plate.

Information on required timing on replacement

As mentioned above, there are currently no candidates for alternative materials, and it is necessary to advance the development of materials that achieve PFAS equivalent performance without increasing user cost or environmental impact during operation.

Building on previous research findings, we will continue the investigation for alternative materials. Because it is very difficult to reach the target simply by substituting materials alone, we believe that it is necessary to review the structure and mechanism of inkjet printers/printers, such as the maintenance mechanism of the print head, as well as to simultaneously develop inks to accommodate these changes.

Thus, adding to the scope not only the development of alternative non-PFAS materials but also a redesign of the printing system, we believe that a minimum of 12 years is necessary, approximately 7 years for the development of materials and systems and 5 years for the confirmation of mass production of materials and the evaluation of their deployment in various products.

In case the development of such alternative materials does not go well, we believe that other methods need to be studied in parallel. These studies need to be initiated from scratch, and similarly, a period of about 12 years may be required.

Information on cost of substitution

The costs of substitution are more than 100,000 euro per kg substituted PFAS.

See confidential appendix for more details.

Substance name and tonnage

Perfluoropolyether and combinations of perfluoropolyether with other polymers are used. See confidential appendix for more specific details.

Information on emissions to the environment

Printheads can either be manufactured in the EU or manufactured outside the EU and imported with the printer itself or supplied as spare parts for replacement.

During coating of the nozzle plate, the solution evaporates into a chamber that is exhausted by the building's air handling system. The oven is also vented to the building air handling system. Small amounts of evaporated fluorinated solvent are currently not captured. Unused coating solution is disposed off as hazmat chemical waste.

The print heads are loaded into the printer and consumed. PFAS is a component hat is integrated in/coated on the printhead's nozzle plate, so there is little risk of it being released outside the printer.

Cartridges that have reached the end of their life or run out of ink are collected or disposed of as waste.

Measures to minimise release into the environment

The Electrical and Electronic Waste (WEEE) Directive requires the collection and safe recycling of end-of-life electronic products. When considering recycling, it is important to ensure long-term durability. Alternative materials will not be as durable as PFAS, and it is expected to be difficult to reuse usable parts of recovered print heads.

With the collection of cartridges/printheads and the very low concentration of PFAS in the printhead the emissions to the environment are considered to be very low.

As described above, the use of PFAS in printers is unlikely to significantly increase environmental pollution. The ban on PFAS used in print heads risks generating more waste due to the shorter life time of printers and printer parts.

Proposed derogation

No alternative is available or known. New substances have to be developed. An exemption for a period of 12 years is needed.

The following text is proposed for the exemption:

Paragraph 1 and 2 shall not apply to fluorinated compounds, fluorinated resins and perfluoropolyethers which are PFAS for use in inkjet printer print heads until 13.5 years after EIF

1.2 Sealing materials, valves and pumps in inkjet printers

General summary of the application category

In all inkjet printers the parts that are in direct contact with ink must be resistant to that ink. In small home office printers, the ink system is small and only a few parts in the ink reservoir and in the print head are in direct contact with ink. In larger printers there are more parts with ink contact, for example tubes, pumps, valves etc. PFAS is typically used for parts that must be flexible as well as ink-resistant. Examples of these parts are:

- O-rings: a non-leaking connection between different components of the ink system is of high importance. No ink may leak out of the printer during its lifetime. Proper sealing is provided by flexible rubbers
- Tubing: in small printers, the ink supply is mounted on the printhead. In large printers the ink supply is in a fixed location separated from the moving printhead. Because of the printhead movement, flexible tubing is required
- Pumps and valves: interior parts of pumps and valves are intended to move and must also provide a good sealing to prevent leaking.

These flexible parts are made of plastics or rubbers. Many plastics and rubbers show an interaction with ink. Over time they can become brittle, beak up or dissolve, ultimately leading to breakdown of the printer or even leaking of ink from the printer. Rubbers may swell due to interaction with ink. Swelling leads to deformation of the rubber and can ultimately result in leaking of ink from the printer. Leaking will damage the property of customers with stains that cannot be cleaned again. It can also lead to safety issues because of exposure of customers to hazardous materials. This must be avoided at all times.

Often PFAS plastics and rubbers have to be chosen because of their resistance to ink and other liquids. These other liquids that are handled in a printer include primers, coolants and varnishes.

Alternatives

In general there are two groups of materials that are flexible and resistant to ink during printer life time: polyethylenes and PFAS. Very often a fluorinated substance is the material of choice.

For tubing an inner layer of polyethylene can be used as an alternative. It is expected that it is possible to change the printer design and replace PFAS tubing with a PFAS-free alternative in new printers before the end of the transition period.

For O-rings a rubber material is required. Non-PFAS rubbers include for example EPDM, silicones and NBR. Non-PFAS rubbers have insufficient resistance against important ink ingredients.

One category of inks is the UV-curable ink. It contains acrylates and photo-initiators. After initiation with UV light, a polymerization reaction starts. The acrylates are the monomers and join together in the polymer network resulting in a dry and very robust in layer on the paper or other substrate.

Most rubbers are not resistant to acrylates (acrylic acid esters). Information on the chemical compatibility of different types of rubbers and plastics is widely available on the internet. See footnote[6] for examples. It can be seen that there is some resistance with polyethylene and

[6] https://dutchwatertech.net/en/kenniscentrum/chemical-resistance-epdm/

polyamide and good resistance against acrylates for fluoroplastics. Non-fluorinated rubbers are not compatible with acrylates. Although a single rubber might be resistant to a single acrylate, they are not compatible with the acrylate mixture in UV curable inkjet inks. FKM rubber (a fluorinated rubber) is not even resistant to all acrylates.

Our actual experience in practice confirms the information that non-fluorinated rubbers cannot be used in combination with UV curable inks: either the rubber is deteriorated by the ink or components of the rubber dissolve in the ink and make it unusable. Even standard FKM rubbers are affected by the ink. The more fluorinated FFKM or special grades of (F)FKM like peroxide cured (F)FKM or PTFE coated FKM are the only suitable rubber materials for UV curable inks.

The other main category of inkjet inks, besides UV curable ink, is the aqueous ink. On the paper, this ink is not cured by polymerization but dried by evaporation of water and other solvents. Sometimes the printer jets a primer liquid in combination with these inks. In general the ingredients in these ink are “milder” than those in UV curable inks and more rubber materials are compatible with these inks. However there still are some ink and primer formulations for which only fluorinated rubbers can be used safely. An example can be seen in the confidential appendix.

The test results in the appendix are in line with other tests that have been performed. The non-PFAS EPDM rubbers are suitable for use in combination with several aqueous inkjet systems, but not with all. For some applications in aqueous inkjet only special grades FKM rubbers and FFKM rubbers can be used safely.

Pumps and valves also contain some polymer material. Two metal parts cannot move along each other and at the same time provide a sealing that does not allow the liquid to pass. A polymeric gasket, seal or seat is always used. In diaphragm pumps the diaphragm is made of a flexible material, a polymer. As for O-rings, for UV curable inks and for some aqueous systems only fluorinated rubbers are inert to the ink and can be used in pumps and valves. If a plastic material is used, polyethylene has insufficient mechanical strength to withstand the frequent movement. This makes fluoropolymers like PTFE the only suitable material.

Similar to the situation of O-rings, not all inkjet printers will require PFAS materials for all pumps and valves. In some cases EPDM rubbers can be used or a gear pump can be used instead of a diaphragm pump. Although it leads to a significant increase in cost price, it leaves out the diaphragm. Nevertheless, gear pumps are not compatible with UV curable ink. They break down quickly.

Stop using UV curable inks and move to aqueous inks is also not an option. Both ink systems have their own application range. UV inks provide a better robustness, water resistance and adhesion to non-paper media. For printing books and paper document aqueous ink can be used. For outdoor applications and several non-paper application UV ink cannot be replaced by aqueous ink.

Currently there are no other materials known that can serve as replacement for the PFAS materials in O-rings, valves and pumps. New materials will have to be developed and no quick solution is foreseen. A derogation for 12 years is required with the possibility to extend if no suitable materials have been developed after 12 years.

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https://www.kendrion.com/fileadmin/user_upload/Downloads/Datasheets_Operating_instructions/Valves_Fluid_Control/Chemical-resistance-valve-technology-Kendrion-EN.pdf
https://www.fernco.com.au/wp-content/uploads/2022/07/Fernco-Rubber-Chemical-Resistance-Chart-V002JUL22-LR.pdf

Substances and amounts

The substances involved are PTFE, PVDF, FKM and FFKM.

For annual volumes, see appendix.

Emissions

Emissions to the environment are not expected during the lifetime of the article. The are no volatile PFAS components, there is no emission. Only in the waste phase the materials will be discarded. The printers are treated as electronic waste and will be handled and disposed of according to all locally applicable regulations.

Proposed derogation

No alternative is available or known. New substances have to be developed. An exemption for a period of 12 years is needed.

The following text is proposed for the exemption:

By way of derogation, paragraphs 1 and 2 shall not apply to fluoropolymers for use in sealing materials, valves and pumps in inkjet printers until 13.5 years after EIF.

1.3 Factories for ink and printer components

General summary of the application category

Just like in any other chemical factory, there are several uses of PFAS in the factories where inks are manufactured. Those parts of the equipment that come into contact with ink, its ingredients or other chemicals must be resistant to these chemicals. If there is an interaction between the material and the chemical, the material will start swelling, deforming, degrading or dissolving. The result is that the product gets contaminated with the equipment material and even worse, the equipment will start leaking.

For rigid materials, stainless steel is a suitable material. For flexible and moving parts plastics or rubbers must be used. As already described in the section about the use of PFAS in inkjet printers there are only a few materials that are resistant to all inks. For an ink factory the situation is more critical because ingredients are processed in their pure form (instead of only diluted in the ink) and sometimes at elevated temperatures. Only fluorinated materials are resistant against all ink ingredients.

PFAS therefore have to be used for example in:

- Valves (PTFE ball valve seats allow opening and closing of the valve while ensuring non-leaking when it is closed)
- O-rings (used for closure and sealing of lids, connectors etc)
- Diaphragm pumps (the diaphragm is moving and must be flexible)
- Gaskets (rotating parts like the axis of pumps and stirrers)

- Flexible tubing (rigid piping is not possible when equipment parts are moving)

Printers contain several components that require special manufacturing processes. These components include printheads, photoconductor drums or belts, fixation rollers etc. The manufacturing process includes chemical processing using solvents and other liquids. When certain solvents are used and especially at elevated temperatures the only flexible materials resistant to these chemicals are fluoropolymers.

Alternatives

Because of the required flexibility and sealing properties, only plastics and rubbers can be used. These plastics and rubbers must be able to resist the chemicals they are in contact with.

The type of plastic and rubber that can be used depends on the chemical and on the temperature of use. When the medium is water, non-PFAS rubbers can be used for sealing. Examples of non-PFAS materials are: EPDM rubber and silicone rubbers.

As explained in the section about ink handling components in printers, for several applications only fluorinated materials are not affected by ink and ink components. Currently no alternative is known. PFAS materials that are used for this application include

- PTFE (9002-84-0)
- PVDF (24937-79-9)
- FKM
- FFKM

Currently there are no alternatives known. The suppliers of the process equipment and parts do not have suitable PFAS-free parts available. If an alternative has to be developed, first the material has to be developed, then the manufacturer of the equipment has to design equipment using the new materials. When new equipment parts are to be used in existing equipment it usually does not fit in the same way as the old part. To some extend the piping and the connections have to be changed. Considering that there are several thousands of parts with PFAS in a factory (a first count in our ink factory resulted in over 2000 parts; probably still incomplete), it is a significant effort to replace a PFAS-containing part by a future PFAS-free part once the old part fails. So even after PFAS-free equipment parts would become available it will take time to make the factory suitable for using them. Therefore a 12 years exemption is requested, with the possibility to extend the exemption if no alternatives are available yet after 12 years.

Amount

The articles can either be fully made of PFAS or have a PFAS coating. The total PFAS usage in a typical manufacturing site is not exactly known but is estimated to be around 100 kg or a few hundred kg per year. The number of toner and ink manufacturing sites in the EU is limited. The total usage in toner an ink manufacturing is not expected to exceed one or a few tons per year.

Emissions

Since the materials involved are all polymers with high molecular weights, there is no evaporation or emission to the air. When the equipment parts are end of life, they are discarded as waste metal.

Consequences when no exemption is granted

When no exemption is granted there is no more manufacturing of ink and printer components possible in the EU. It will have to move to non-EU countries. This will have a huge impact on the EU economy and will lead to extremely high costs for printer companies to build new factories outside the EU.

Proposed derogation

No alternative is available or known. New substances have to be developed. An exemption for a period of 12 years is needed, with the possibility to extend this exemption if no alternative materials have been found after 12 years.

The following text is proposed for the exemption:

By way of derogation, paragraphs 1 and 2 shall not apply to fluoropolymers for use in factories for ink and printer components until 13.5 years after EIF.

1.4 Electrophotographic printers

General summary of the application category

In electrophotographic printers and copiers, PFAS materials are used in parts that come into contact with toner or are at the core of the printing process and are subjected to high stress such as high temperature or high voltage. These are for example the charge roller, photoconductor (or photoreceptor) drum, intermediate transfer belt (ITB), fuser parts. See the figures below for the location of these parts in the printer. More explanation about the function of a printer can be found in several open sources on the internet.

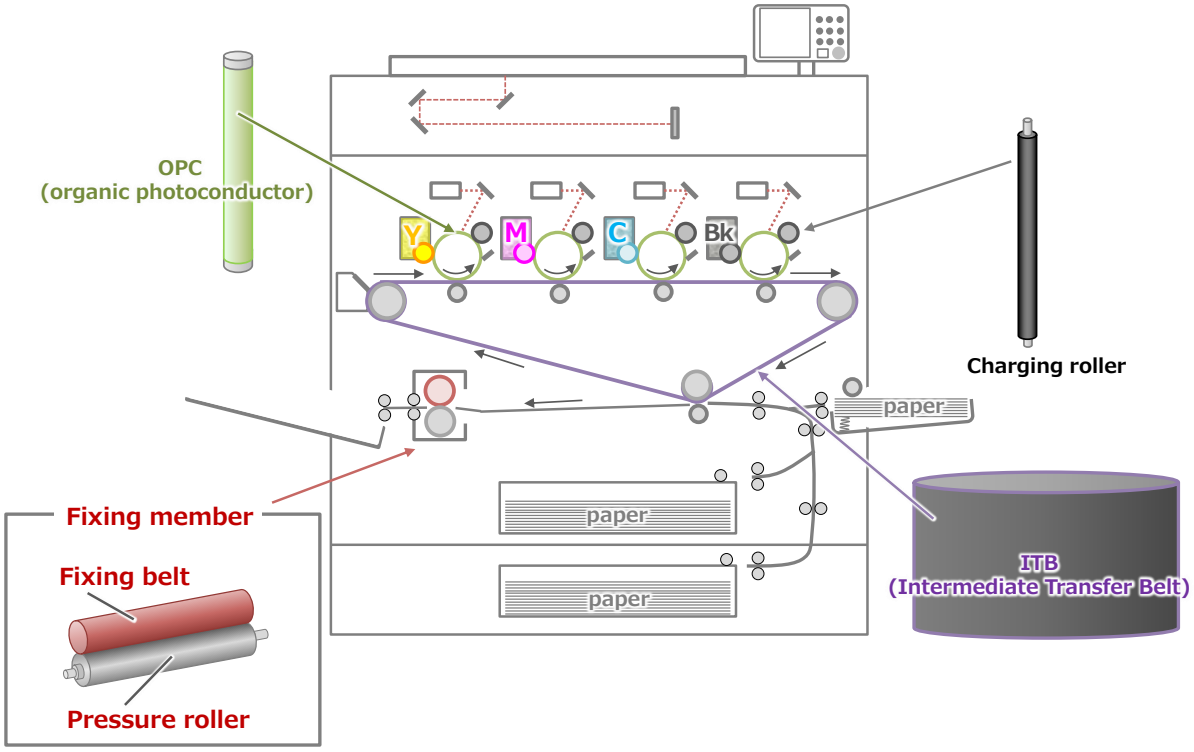

Figure 2 Electrophotographic printer (1)

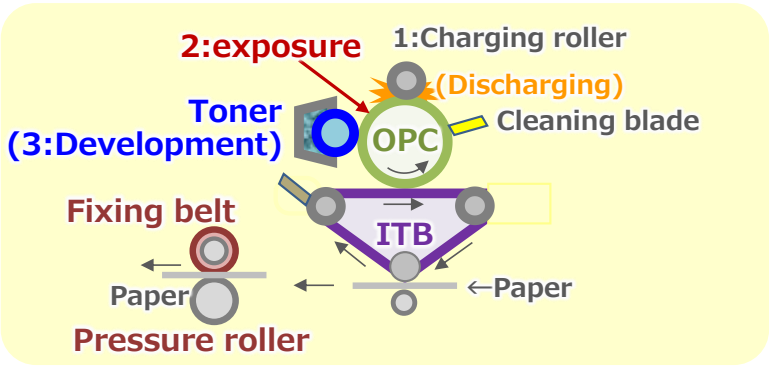

Figure 1 Electrophotographic printer (2)

With the current technology, there is no substitute alternative that can maintain the same quality as PFAS materials, and if PFAS materials become unavailable, the image output becomes impossible in the electrophotographic device. As a result, there is a risk that the product is no longer usable as a printer.

For the charge roller, the photoconductor drum and the ITB the available non-PFAS alternatives have not yet achieved sufficient performance. However, with technological

progress the challenges could be overcome in the future. For the fuser parts the alternative components have no prospect of becoming functioning alternatives.

Technical function

The charge roller, photoreceptor drum, intermediate transfer belt (ITB), and fuser parts used in electrophotographic products need to have a good releasability with toner. Toner consists of small particles and in order to avoid contamination of the printing system, it must be possible to release these particles again from the roller, drum, ITB and fuser parts. To improve the releasability with the toner, a PFAS compound is contained as an additive/filler in the surface layer. This PFAS compound also reduces the required torque and reduces the physical wear of the component. It is inert to the solvents used in component manufacturing.

Charge roller, drum and ITB

In the charge roller, photoreceptor drum and ITB, the surface in contact with the toner uses electrostatic force to move the toner. In other words, the toner and parts slide against each other while constantly being exposed to high voltage electrical energy and friction energy. These components must continue to exhibit releasability under severe conditions. Fluoropolymers, which are PFAS, are chemically stable and durable, and can exhibit release properties for long periods even under these harsh conditions. In addition, the latest electrophotographic products tend to use smaller toner for better image quality. This is to reduce the graininess of the image and to reduce the amount of toner used. On the other hand, the smaller the particle size of the toner, the less the release property of the toner, and therefore, the more waste toner remains. Fluoropolymers can reduce the amount of waste toner in the first place, so that they can meet the ever-increasing demand for reducing toner waste. In addition, PFAS compounds in the charge roller, photoconductor drum and ITB also have a friction-reducing effect, which can reduce the amount of wear on these components and reduce the frequency of replacement, thereby contributing to waste reduction. Depending on the customer's usage, it is quite possible that a component that can last from six months to the life of the machine using fluoropolymers, etc. will only last for a few days or months without PFAS.

Fuser parts

The fusing process is a process in which the toner is instantly melted and the melted toner is soaked into the paper fibres to fix the toner on the paper. At this time, the fuser contacts the toner and applies heat (up to approx. 240 °C) and pressure (up to approx. 0.6GPa) to bring the toner into contact with the paper. The toner containing resin or wax melts and penetrates into the paper fibres. At this time, the toner should remain on the surface of the paper but not on the surface of the fixing member. For this reason, it is necessary to have a material that maintains the releasability to the resin under high temperature and high pressure, and whose performance can be obtained stably over a long period of time. In addition, materials are limited in the sliding part with the heater, which is another key part in the fixing process. In the sliding portion between the heater and the fuser belt, the material and grease must be a material that remains highly slidable even at high temperatures up to approx. 270 °C. The fluoropolymers and fluoropolyethers currently in use are chemically stable and have excellent heat resistance, as well as excellent releasability and slidability, and their performance is stable over a long period of time.

Fuser parts: Rollers in high-speed printers

In high-speed printers that have monthly print volumes of several hundreds of thousands up to millions of prints per months, contamination of the fuser system can be a significant

problem. Small amounts of additives from the paper can be transferred to the fuser belt during the fusing of the toner. Because of the large printing volume, these small amounts can build up to significant quantities over time. The presence of substances that originate from the paper cannot be influenced by the printer manufacturer. However, in these high-volume printers cleaners are included that clean the fuser belt. Unfortunately, not all substances can be cleaned for 100%. Some substances can migrate to the rollers in the fuser unit (e.g. the pressure roller or one of the rollers inside the fuser belt). When these substances accumulate, they can cause swelling of the outer layer of the rollers, which is made of rubber. This swelling is not evenly distributed along the roller. One part of the roller will get a larger diameter then another part of the roller. This will result in serious printing problems. Examples of these problems are: a cleaner that does not function on the complete width of the belt anymore, speed differences across the fuser belt or temperature differences across the fuser belt. This results in print quality problems or severe pollution of the printer to the extent that the printer will fail.

To prevent the build-up of contamination in the rollers, the outer layer of the rollers is covered with fluoropolymers. Fluoropolymers are resistant to most other chemicals. In this application they are inert to swelling due to contaminants. Fluoropolymers are also resistant to the temperatures of up to 175 °C in these systems. And fluoropolymers are strong enough to withstand the mechanical forces in the system.

Alternatives

No alternative drop-in raw material is known. Requirements for alternatives are constrained by current product portfolio and subsystems. Any change may require customized changes in other materials/subsystems to enable.

For the charge roller, photoconductor drum and intermediate transfer belt (ITB) alternative materials have been investigated. The performance is not sufficient yet, but with further progress in research the challenges could be overcome.

Alternate fillers explored in the past include particle fillers (SiO2, TiO2, TiO2 core with Si shell, hydrophobic silica), which required customized surface treatments to reduce electronic effects. Silica could be a potential option for both photosensitive and non-photosensitive layer applications. The addition of plasticizers or high molecular weight monomers to reduce surface energy and improve cleaning were explored and may enable removal of PFAS, however, reduced part life is likely, and the effect on the electronic performance is unknown. If the same quality as PFAS materials cannot be achieved, it may be necessary not only to change the materials of the above components but also to redesign the unit configuration and control mechanism of the whole electrophotographic machine.

For the fuser parts, there is no expectation that the technical problems with the available alternatives will be overcome. The development of alternatives will have to start from scratch again, as there are currently no alternatives that can play the full role of PFAS. In addition, even when the properties required by the material quality are not achieved, the fundamental principle of fusing cannot be changed, so that the lack of properties cannot be compensated by redesigning the machine. So far, no replacement is in sight.

See the confidential appendix for more details.

Information on required timing on replacement

There are currently no candidates for alternative materials, and the development of materials that can achieve comparable performance needs to start from scratch.

In the past, the implementation of an alternate PFOA-Free PTFE filler in a photoconductor to comply with regulations took 3 years to source material, qualify in manufacturing process, and validate performance across the product portfolio. In this case it was only a relatively small change while the main material (PTFE) remained the same. The development of a totally new material will require longer time.

In addition to the search for alternative PFAS materials to achieve equivalent release and lubricity, it will take approximately seven years to develop the required electrical, optical, and durability fittings for each component. It would also take five years to evaluate the production process to produce each component with alternative materials for PFAS, the start-up of the production equipment and its deployment to various products, including current products. As a result, we believe a total of 12 years is at least necessary.

Also, if the development of alternative materials does not go well, it may be necessary to develop materials that have tried an entirely different approach, such as inorganic surface materials, or other means that do not rely on material properties. In that case, it will be necessary to develop manufacturing equipment, and there is a possibility that even 12 will not be enough.

References regarding industry approach and complexity of replacement:

The extract below from The History and Development of Organic Photoconductors for Electrophotography by David S. Weiss[7] shows the complexity of replacing the filler, with competitors employing their own proprietary methods.
"Ricoh has described an approach where the OCL is filled with semiconductor oxide particles, Al2O3 for example, to increase its hardness. The filler content had to be optimized to permit some wear of the layer, and additives such as antioxidants had to be used to prevent increased conductivity leading to image spread. Silsesquioxane sol–gel OCLs have been commercialized by Eastman Kodak. The sol–gel is a solution coated onto the OPC where drying and partial curing occurs. The overcoated OPC was subsequently thermally cured to optimize the crosslinked structure for hardness, brittleness, and conductivity. The latter was accomplished by the addition of LiI but this caused image spreading at high humidity due to increased conductivity. This was minimized with formulation optimization. More recently hole transport functionalities have been incorporated into the sol–gel such that the OCL will function as a second CTL. Witt and co-workers (Sensient Imaging Technologies and AEG Elektrophotografie) have described a sol–gel OPC overcoat. The overcoat (1–2 μm) has little effect on the dark and photodischarge characteristics of the OPC and significantly improved the OPC wear characteristics. One technical obstacle is that the sol–gel formulation crosslinks with time, so in dip-coating applications the pot life is limited."

US20140051018A1 - Canon patent reference
JP2016184059A - Konica patent reference
JP6123225B2 - Ricoh patent reference

Costs

Information on the costs can be found in the confidential appendix

[7] Weiss, David. (2016). The History and Development of Organic Photoconductors for Electrophotography. Journal of Imaging Science and Technology. 60. 10.2352/J.ImagingSci.Technol.2016.60.3.030505

Substances and amounts

The substances are all fluoropolymers. See attached confidential appendix for details on substances and volumes.

Emissions

These components are manufactured both in the EU and outside the EU and are included in the electrophotographic printer. They are also replaced by service personnel as consumables and service parts.

Despite the fact that copiers and printers use about 0.0001% to 0.1% PFAS by weight (depending on the type of printer), they play an almost crucial role, especially when it comes to fuser parts. Therefore, if the use of PFAS is effectively prohibited, the entire copier must be discarded despite the use of PFAS of at most 0.1%.

According to International Data Corporation (IDC) estimates, about 17 million copiers and printers that use electrophotography and inkjet are shipped to Europe annually. These are estimated to be approximately 500,000 tons by weight. If the number of copiers and printers already on the market is estimated to be about 5 times the annual sales, the number in operation would be 85 million. It is estimated that if all of these were discarded, 2.5 million tons of waste would be generated when the regulations were implemented. The impact on the environment is enormous.

In copiers and printers, parts including PFAS do not come into contact with people. The aforementioned fuser parts, photoreceptor drums, ITBs, and charge rollers are not touched by people during the service life of the copier, except by the service technician who replaces them. There are no volatile PFAS components, there is no emission.

In addition, because the fluoropolymers are chemically stable, it is almost impossible for them to react chemically with the human body when touched. Contact with human bodies and the environment is limited after disposal, but as mentioned above, the WEEE directive is followed and the risk of contamination is minimized. It is unlikely that PFAS caused by copiers and printers will spread into the environment and become a source of pollution that threatens the human body.

Proposed derogation

No alternative is available or known. An exemption for a period of 12 years is needed.

The following text is proposed for the exemption:

paragraphs 1 and 2 shall not apply to fluoropolymers and perfluoropolyethers for the use in drums, rollers and belts in electrophotographic printers until 13.5 years after entry into force

1.5 Paper guiding parts

General summary of the application category

In high speed printers the paper is transported through the printer by many different parts. Because of the high speeds there can be high friction forces between the paper and the printer parts. In some cases this can lead to contamination of these parts with toner and ink. When the contamination builds up during use of the printer, it will damage the prints and eventually lead to paper jams. This is often solved by using low friction and non-stick PTFE parts or PTFE coatings on parts.

Technical function

Paper guiding rollers

“Continuous feed printers” do not print on cut sheet papers, but on large rolls of paper that are cut into sheets after printing. These are high speed production printers. Monthly production print volumes reach several millions of pages per month. The inkjet printing process on a continuous paper feed includes a paper transport system with a series of rollers to pass the paper through the first print station (with sub functions inkjet print heads, drying, cooling), a turning unit and the second print station for two sided printing. These printers are well-balanced systems and are the result of over a decade of research, development and step-wise product improvements. In this printer some paper transport rollers are coated with PTFE.

The printing process includes following main functions:

- jet ink droplets on paper side 1 by drop on demand printheads
- dry ink on paper to achieve sufficient robustness of the printout
- cool down paper to allow further processing
- turn over paper side
- jet ink droplets on paper side 2
- dry ink to achieve sufficient robustness of the printout
- cool down paper to allow further processing

See confidential appendix for a more details.

Technological innovations to improve colour gamut and resolution have been driving factors for successful marketing of new inkjet production printing systems. In order to achieve these targets new ink recipes have been developed.

Ink composition is constrained by many factors like environmental requirements (water based inks), print quality, incl. e.g. colour gamut and good ink adsorption on a wide range of papers, stable jetting properties of the picolitre-size droplets, long storage stability. Also drying properties are taken into account but need to be balanced with all other key aspects. Due to these limitations ink has not yet reached full robustness after the fixation unit. Robustness of the print will come with time, but when the paper is still in the printer, immediately after drying, the ink tends to stick to contact surfaces. This results in problems with ink pollution on the transport rollers. To prevent ink pollution and deterioration of print quality an anti-adhesive coating based on PTFE is used for the rollers after the drying unit.

Paper heating and guiding plates

In high speed cutsheet printers, metal plates are used to guide the paper and/or to heat the paper. The warm paper will move along these plates. Pollution of these plates with toner must

be avoided. Also pollution from pre-printed logos and images on the paper must be prevented. Since these printers print high monthly volumes, small amounts of toner pollution on the plates can quickly build up to larger amounts. This larger toner pollution on the plates will damage (scratch) the prints or can lead to paper jams. The pollution can be avoided by using a PTFE coating on the plates.

Other paper guiding parts

There are other small components involved in the transport of the paper through the printer. For those parts that come into contact with the printed paper and have high friction with the paper, toner or ink contamination will build-up leading to damaged prints and paper jams. Also in these cases including PTFE in these parts lowers the friction, provides non-stick properties and solves the contamination problem

Alternatives

No alternatives are known at this moments. If the PTFE is left out and standard materials are used, there is a build-up of contamination that will eventually lead to damaged prints and paper jams. Cleaning these parts is time consuming and not always possible. The build-up of contamination can be even within a few hours of printing. Leaving out the PTFE is not an option. Alternative low-friction and non-stick materials have been investigated but have not been successful so far.

See confidential appendix for more details on materials that have been tested.

Costs and timing of replacement

The feasibility of alternative coating materials without PFAS is unclear at this moment. The known candidates have been tested and failed. There are no other candidate materials known.

Technological innovation could allow other solutions in future. However, the risk of not finding a suitable solution without PFAS is estimated high, besides the fact that industrialization of a technological innovation requires high additional efforts and long lead times.

The costs of alternatives materials cannot be estimated because an alternative material is not known. However, an estimation can be given of the resources required to implement a new material in printers. As an example, the costs for a change in the coating of the paper guiding rollers in continuous feed printers is given.

Developing an alternative coating will require more than 5 years due to the required improvement iterations and lifetime testing. In a first step material candidates need to be identified, samples have to be prepared by the supplier and evaluated with respect to anti-adhesive properties and potential side effects on paper transport stability. Each iteration would take at least 6 months. Lifetime testing would start under laboratory conditions within R&D. After successful completion a customer staging is needed with min. 1 year duration. Including preparation of serial production and manufacturing ramp up 3-5 years lead time are estimated for market introduction. However, since all known candidate materials have been tested and were not suitable, there is a high risk that no solution compliant to the PFAS restrictions can be found. In that case we have to wait for new materials to enter the market. In that case it can easily take more than 10 years before an alternative is implemented in our printers.

An alternative approach could be based on a complete redesign of the printing process including a change of the ink or toner recipe together with modification of printing, drying and cooling process. A modification of these process means that the fundamental design of the printer has to be changed. This will take at least five years and will require at least 50 man

years. Given the uncertainty of the feasibility it is also possible that the investment of man years will be twice as much. The total development costs are between 12 and 25 million euro for the coating of the paper guiding rollers in a single printer type only. For the paper guiding plates and other parts similar numbers apply. A redesign of would also have costs in the same order of magnitude for a single printer type/model series.

Substances and amounts

See confidential appendix.

Emissions

Since the materials involved are all polymers with high molecular weights, there is no evaporation or emission to the air. When the equipment parts are end of life, they are discarded as waste metal. Due to abrasion there will be some wear of PFAS containing components. It is estimated that less than 50% of the PFAS material will be released into the environment in this way.

Required exemptions

Changing the PFAS material has an uncertain lead time because there are no PFAS-free candidates yet. New materials have to be invented. An exemption for 12 years would be required.

A fundamental redesign of the printing processes, eliminating the need for PFAS would cost millions of euros. When taking into account the current annual emission of PFAS use for ten years, a full redesign of the printing system only for this purpose would cost more than 50,000 euro per kg avoided PFAS emission. This is not proportionate if this redesign is done only for avoiding PFAS. However, it is expected that a new generation of printers will be developed and ready to place on the market ultimately in 2035. The substitution of PFAS can be included in the development of this next generation.

An exemption for the use of PTFE as coating on paper guiding parts in printers is required until 2035.

Proposed derogation

paragraphs 1 and 2 shall not apply to fluoropolymers for the use paper guiding parts in printers until 1-1-2035.

2. PFAS material in Lithium-ion batteries

2.1. Cathode and separator binder material for Lithium-ion battery cells

Name of PFAS substance(s) Polyvinylidene fluoride (PVDF), Polytetrafluoroethylene (PTFE), Ethylene tetrafluoroethylene (ETFE) and Fluorinated ethylene propylene (FEP)

CAS Number(s) 24937-79-9, 9002-84-0, 25038-71-5, 25067-11-2.

General summary on the application category

All Lithium-ion battery cells use PVDF or PTFE as the binder material for all types of positive electrodes (cathode). They are also widely used in separators. These PFAS binder materials help to improve energy density, durability, reliability, and usable lifetime of the battery. It also prevents them from self-discharging when idle.

Product durability/useful life is a key focus of policy efforts as part of the Circular Electronics Initiative and has been a key feature in the review of Ecodesign Regulation 617/2013 (Lot 3) - Computers and Computer Services. The durability of batteries potentially limits the lifetime of the device it is powering, if battery replacement is economically not feasible, or technically not possible. This may lead to early disposal of devices. Prolonging life is particularly important for lithium-ion batteries (LIB), not only do LIB contain a high amount of critical materials such as cobalt, they also involve substantial environmental impacts during their manufacturing (Source, JRC, 2018, https://publications.jrc.ec.europa.eu/repository/handle/JRC105156).

For the cathode, many other binder materials have been evaluated as replacements for PVDF and PTFE, however all other materials have been found to oxidize at the high voltage at the positive electrode (RCOM Ref. 3925, Supplier Survey 2023). In practice, this would mean that batteries in electronics would need to be replaced very frequently, leading to a corresponding growth in e-waste, battery waste, and demand in critical raw materials. Restricted high-voltage operation also means low run time for any portable devices, which would not meet consumers' daily use requirement.

Although the PFAS binder comprises only a small portion of the composite electrode (typically 2–5% of the mass of the electrode), the binder plays an important role in battery performance. The PFAS binder:

- Helps to disperse the active material and the conductive additive in the solvent during the fabrication process, enabling a homogeneous distribution of the slurry.
- Holds the active material and the conductive additive together and connects them to the current collector, ensuring the mechanical integrity of the solid electrode without significantly impacting electronic or ionic conductivity.
- Acts as an interface between the composite electrode and the electrolyte. In this role, the PFAS binder protects the composite electrode from corrosion and the electrolyte from depletion while facilitating ion transport across this interface.
- Tailors the viscosity of the slurry to allow a smooth coating onto the current collector during electrode manufacturing.

PVDF and PTFE have several unique properties that enable them to fulfil these critical roles[8]:

- Mechanical properties, including stiffness, toughness and hardness as well as good adhesion to the active material, the conductive additive, and the current collector. The positive electrode binder must be able to withstand the forces that result from the expansion and contraction of active materials during charge/discharge cycles.
- Thermal properties, particularly thermal stability, are also important, both for the high temperatures commonly used for curing and drying during electrode fabrication and also for operation of the battery at various temperatures.
- Good dispersive capabilities are important to help distribute the slurry evenly over the current collector during fabrication,
- Chemical and electrochemical stability are essential properties to enable the binder to function for long periods and over numerous cycles without degradation of the battery. The positive electrode binder must not react with any other components or intermediates formed during operation. In particular, the positive electrode binder must remain stable at the high and low voltage potentials experienced by the cathode. This stability guarantees its safe use in the electrochemical environment of the lithium cell.

Many academic-level and lab-scale investigations are currently looking at replacing PVDF as the cathode binder material but remain at this stage small scale research - there is still a significant gap before these can be tested, proven, produced, deployed, and sourced at the large mass production scale needed to replace PVDF.

For the separator (which is an indispensable part of batteries which separates the negative electrode from the positive electrode to prevent internal short circuits, whilst not participating in electrochemical reactions), PVDF is used because it offers excellent adhesion in liquid electrolyte which in turn ensures interface stability resulting in better performance (lower impedance and degradation) and durability. Further, the polarity of the C-F bond in the PVDF is high. While PMMA has been trialed to replace PFAS as the separator binder coating, there are issues with accelerated decay in the later stage of cycling and degradation of the negative electrode interface under high-rate charging.

A PFAS restriction without derogations for batteries will seriously limit the Green Deal and prevent Europe from achieving a net zero economy by 2050. The European Green Deal is one of the world's most ambitious climate policies to usher the European Union and its Member States into a net zero economy by 2050 by decoupling economic growth from fossil fuel dependency. The Green Deal relies on batteries to achieve objectives for low-emission mobility, decarbonized energy generation and digitalization.

Batteries have been identified by the European Commission as a strategic value chain. The Commission states: ""Batteries are thus an important source of energy and one of the key enablers for sustainable development, green mobility, clean energy, and climate neutrality".[9]

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Refer to RCOM Ref. 3925 (RECHARGE submission) - Section 4 PFAS consumption in tonnes and emissions during battery life cycle.

[8] RCOM Ref. 3925
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_5469_2023_INIT&from=EN

The key functionalities provided by PFAS for the relevant use[10]

1. Mechanical properties, including stiffness, toughness and hardness as well as good adhesion to the active material, the conductive additive, and the current collector.
2. Thermal properties, particularly thermal stability.
3. Good dispersive capabilities are important to help distribute the slurry evenly over the current collector during fabrication
4. Chemical and electrochemical stability enable the binder to function for long periods and over numerous cycles without degradation of the battery at the high and low voltage potentials experienced by the cathode.

For which uses of PFAS is there no alternative?

Outlook: No alternative has yet been identified.

R&D activity: refer to details in RCOM Ref. 3925 (RECHARGE submission):

For Lithium-ion rechargeable batteries, PVDF was previously also used as the binder material for the negative electrode as well as for the positive electrode. For graphite negative electrodes (anodes), companies have successfully substituted PVDF with water-based CMC/SBR binder materials. CMC/SBR is now the most common commercially used binder material for the graphite negative electrodes due to its good cell performance, lower cost and reduced environmental impact[11].

For cathodes, no alternatives are available. The European Commission has recently funded the GIGAGREEN research project on dry alternatives and water-based binder systems for the positive electrode which propose to utilise a range of polymers including CMC/SBR, poly(acrylic acid), sodium alginate, polyurethanes and catechol-bearing polymers[12]. Whilst these initial research studies have indicated that these aqueous binder systems may have good adhesion properties, further research and development is required to investigate whether these alternatives have adequate chemical, mechanical, and electrical properties[13]. There are significant concerns about whether water-based CMC/SBR technology will have the necessary rheology and stability to match with today's positive electrode active materials such as LCO, NMC, NCA, LNMO, LFP. There are also specific concerns about the use of water in the slurry production and the electrode coating, drying and calendaring processes, particularly if the water is not completely removed before the battery is assembled.

The German Government has funded the DigiBatt Pro 4.0[14] research project which also includes development of water-based binder systems for positive electrodes. As part of this research project, positive electrodes of around 100 metres in a lab scale with roughly 1/100 to 1/50 the scale of mass production have been produced using a nickel rich NCM cathode active material, $LiNi_{0.83}Co_{0.12}Mn_{0.05}O_2$. The cells could be successfully charged and discharged

[10] Source: RCOM Ref. 3925 (RECHARGE submission)
[11] Hawley, W. B., & Li, J. (2019). Electrode manufacturing for Lithium-ion batteries—Analysis of current and next generation processing. *Journal of Energy Storage*, *25*(C), 100862–. https://doi.org/10.1016/j.est.2019.100862
[12] Funding & tenders, Towards the sustainable giga-factory: developing green cell manufacturing processes (GIGAGREEN). (n.d.). https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/how-to-participate/org-details/999999999/project/101069707/program/43108390/details
[13] Cholewinski, A., Si, P., Uceda, M., Pope, M., & Zhao, B. (2021). Polymer Binders: Characterization and Development toward Aqueous Electrode Fabrication for Sustainability. *Polymers*, *13*(4), 631–. https://doi.org/10.3390/polym13040631
[14] "*DigiBattPro 4.0 - BW*" - Digitized Battery Production 4.0 - Fraunhofer IPA. (n.d.). Fraunhofer Institute for Manufacturing Engineering and Automation IPA. https://www.ipa.fraunhofer.de/en/reference_projects/digibattpro.html

1,000 times at 25°C before they fall below 80% of initial capacity[15]. Whilst this research project appears to show promising results for very high nickel content batteries, correspondence with the project partners highlights that:

- Positive electrodes manufactured using water-based binder materials show increasing impedance/resistance with increasing numbers of charging and discharging cycles,
- The stability of the charging and discharging cycles is substantially lower than state-of-the-art positive electrodes using PVDF binder materials,
- The rapid increase in pH alkalinity of the water-based binder materials results in a very short shelf life for the mixed slurries, this would be very challenging for an industrial process as the mixture would go out of specification very quickly.

Further investigation of this research project confirms it focused on a very specific high nickel NCM cathode active material at a moderate cell voltage of 4.2V. There is no evidence that this water-based binder material could be developed to meet the performance targets for positive electrodes with LCO chemistries operated at higher voltages, which is what many electronic devices use today.

It is also important to note that this research project focused on a very specific cylindrical 21700 cell form factor used in certain automotive and power tool applications[16]. Performance in this specific form factor is not directly transferrable to other cell form factors used in other applications. There are many unknowns which would need to be investigated before this technology could be adopted in other chemistries and other form factors, including:

- cycle life and calendar life and impedance growth under wide range of temperatures
- swelling, fast charge cycling is unknown,
- electrode processibility for multilayer pouch cells and uniformity of coating is unknown,
- correspondence with the project partners highlighted that the positive electrodes manufactured using water-based binder materials show higher cell resistance and faster growth in resistance with increasing numbers of charging and discharging cycles with the high nickel NCM cathode active material. This trend is anticipated to become worse when industry moves to cathode active material operating at higher voltage, higher energy and higher power.

Several other research laboratories have reported developments in water-based binder systems for positive electrodes using other polymer materials in limited applications on the lab scale with simple coin cell batteries, but none of these efforts have successfully been scaled up to perform for industry relevant chemistries, cell configurations and production volumes. For example, Lawrence Berkeley National Laboratory reports they have tested polyacrylic acid (PAA) with the cross-linking agent polyethylenimine (PEI) as the binder for sulfur cathodes for LiS coin cells operating between 1.5v and 2.8v for 100-200 cycles[17]. No information is provided on performance in larger cells or industry-scale applications. Furthermore, industry

[15] Radloff, S., Scurtu, R.-G., Hölzle, M., & Wohlfahrt-Mehrens, M. (2021). Applying Established Water-Based Binders to Aqueous Processing of $LiNi_{0.83}Co_{0.12}Mn_{0.05}O_2$ Positive Electrodes. *Journal of the Electrochemical Society*, *168*(10). https://doi.org/10.1149/1945-7111/ac2861

[16] Radloff, S., Carbonari, G., Scurtu, R.-G., Hölzle, M., & Wohlfahrt-Mehrens, M. (2023). Fluorine-free water-based Ni-rich positive electrodes and their performance in pouch- and 21700-type cells. *Journal of Power Sources*, *553*, 232253–. https://doi.org/10.1016/j.jpowsour.2022.232253

[17] Liu, Z., He, X., Fang, C., Camacho-Forero, L. E., Zhao, Y., Fu, Y., Feng, J., Kostecki, R., Balbuena, P. B., Zhang, J., Lei, J., & Liu, G. (2020). Reversible Crosslinked Polymer Binder for Recyclable Lithium Sulfur Batteries with High Performance. *Advanced Functional Materials*, 30(36), 2003605–n/a. https://doi.org/10.1002/adfm.202003605

relevant chemistries such as LCO and NMC have high pH when dispersing in water and this may not be compatible with the binding function of this PAA/PEI binder.

New research papers and grant applications are regularly being proposed to develop alternatives to PVDF as the cathode binder and/or NMP as the solvent. We investigate all these research papers in detail and include comments on all research papers published up to August 2023 in this dossier. However, some research papers may be published after the public consultation closes in September 2023 and where we are not able to comment on them in this dossier.

Furthermore, replacing the PVDF cathode binder likely requires the development of new cathode active material and Aluminium current collectors that are compatible with a new binder and solvent system. Water is known to cause poor cycle life and increased impedance growth in Lithium-ion cells. A new grade of active cathode powder may need to be developed to increase particle surface protection against water.

Replacing the PVDF cathode binder with new binder and solvent also requires development of a compatible electrode and cell manufacturing process and equipment. The necessary process and equipment change at mass production scale is unknown at this point and will be different for different companies depending on which alternative technology they pursue. The performance of mass production line produced PVDF free battery may have significant performance gaps compared with current batteries. Addressing these performance gaps may require a significant number of iterations of materials improvement, production process change and cell performance testing.

Replacing the PVDF cathode binder with new binder and solvent also requires development of a compatible electrode and cell manufacturing process and equipment. The necessary process and equipment change at mass production scale is unknown at this point and will be different for different companies depending on which alternative technology they pursue. The performance of mass production line produced PVDF free battery may have significant performance gaps compared with current batteries. Addressing these performance gaps may require a significant number of iterations of materials improvement, production process change and cell performance testing.

Given the above, we estimate that efforts to develop and commercialise high performance non-PFAS cathode binder, Al foil, active materials and corresponding cell manufacturing processes would take at least 10 years, followed by 5 years to commercialise the new technologies.

PFAS is also used as a binder material on the separator of Lithium-ion battery cells. The separator is an indispensable part of batteries which separates the negative electrode from the positive electrode to prevent internal short circuits, whilst not participating in electrochemical reactions. At present, the most commonly used commercial separators are polyolefin separators, such as polypropylene (PP), polyethylene (PE) and multi-layer composite separators (PP-PE-PP). The layer materials are processed to make them porous by including tiny pores or voids at 35-45% porosity. The typical pore size is 200 nm - 1µm which is large enough for the lithium ions to move smoothly through the separator.

Commercial tri-layer PP/PE/PP separators take advantage of the difference in the melting point of PP (165°C) and PE (135°C), using PE as the shutdown layer and PP to protect structural integrity. When the cell temperature rises near the melting point of the PE layer, the PE layer will melt at a temperature of 135°C and close the pores in the separator to stop the current flow while the PP layer, which has higher melting temperature than PE, remains solid. However, such protection is only effective below the melting point of PP.

To provide better thermal and mechanical stability, commercially available ceramic coated separators have been developed. Ceramic particles, such as alumina, silica, or zirconia can be mixed with polymeric binders and slurry-coated onto the polyolefin separators. In comparison to PP layers, ceramic coatings offer a better electrolyte wettability, which translates into better Li-ion transport through the separator and therefore a better performance of the battery. Although ceramic coatings have proven effective in improving the thermal stability of separators, the effectiveness of the protection is still limited by the thermal stability of the polymeric binder used.

Some companies use PVDF as the binder material for the ceramic coating to provide good adhesion to the electrolyte/composite electrode, as well as providing good adhesion of the ceramic coating to the separator. Other companies have developed non-PFAS binders which also provide good levels of adhesion to the separator and the electrolyte/composite electrode. PMMA is considered as a potential alternative material for PVDF separator binder, but there are issues with accelerated decay in the later stage of cycling and degradation at the negative electrode interface under high rate charging. Some organizations are researching the use of binder-free, thin-film ceramic-coated separators which may be able to provide improved safety for Lithium-ion batteries. Additional time is required for battery manufacturers to study and qualify non-PFAS alternative solutions to ensure performance and safety and to commercialize the technology broadly.

In addition, contrary to what is stated in Annex E (page 416) of the PFAS Annex XV dossier, solid state batteries are not potential non-PFAS alternatives to Lithium-ion batteries. This is because solid state batteries do use PFAS, specifically PVDF and PTFE in the binder within the active material, in solid electrolytes and in gel polymer electrolytes.[18]

Substitution:

Substitution is estimated to take at least 15 years, and possibly longer. This will first depend on the battery industry to develop a suitable potential alternative material. As detailed in RCOM Ref. 3925 (RECHARGE submission), the estimated time to develop and commercialize high performance non-PFAS cathode binder, Al foil, active materials and corresponding cell manufacturing processes would take at least 10 years, followed by 5 years to commercialize the new technologies.

Proposed derogations

Paragraph 2(c) shall apply from (**13.5 years** after entry into force) to PFAS used in **cathode binder materials in Lithium-ion battery cells**. **The European Commission shall review this derogation by 3 years before its expiry to assess whether alternatives are now available or whether further renewal is needed and to publish amendments to the Regulation.**

Paragraph 2(c) shall apply from (**6.5 years** after entry into force) to PFAS used in **separator binder materials in Lithium-ion battery cells.**

[18] Source: RCOM Ref. 3925 (RECHARGE submission)

2.2. Lithium-ion batteries: Socio-economic impacts

The European Green Deal is one of the world's most ambitious climate policies to usher the European Union into the net zero economy by 2050. The Green Deal relies on batteries to achieve objectives for low-emission mobility, decarbonised energy generation and digitalisation. **A PFAS restriction without a derogation for batteries, and without a review clause, will limit the Green Deal and prevent Europe from achieving a net zero economy by 2050.**

Batteries have been identified by the European Commission as a strategic value chain. The Commission states:

'*Batteries are thus an important source of energy and one of the key enablers for sustainable development, green mobility, clean energy, and climate neutrality*'[19].

More than EUR 20 billion has been devoted to the EU battery value chain via the European Commission framework on Important Projects of Common European Interest (IPCEI), the European Investment Bank and research funding in the last few years. Dozens of billions more are available via the European Union InvestEU fund and the European Commission Recovery and Resilience Facility. Over half of all lithium batteries on the EU market in 2022 were produced in Europe, with the continent projected to become the world's second biggest battery cell manufacturer by the end of the decade[20]. As a direct effect, this will require 800 000 workers by 2025[21]. The installation and maintenance of batteries as well as end of life recycling could potentially create between 3-4 million jobs by 2025[22].

- Europe is on track to produce 6.7 million battery electric cars (BEV) by 2032, or just over half of all the cars produced, which is in line with the recently agreed -55% CO2 target for carmakers for 2030 that is expected to result in a 50-60% share of BEV sales[23].
- Half of the lithium battery cells used in electric vehicles and energy storage systems in the EU were already made in the bloc in 2022, notably in Poland, Hungary, and to a lesser extent in Germany and Sweden. Transport & Environment analysis of the battery cell capacity announcements to date shows that Europe can be self-sufficient in battery cells, i.e. produce 100% of our lithium battery cell demand from 2027[24].

[19] REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC. https://data.consilium.europa.eu/doc/document/PE-2-2023-INIT/en/pdf

[20] A European Response to the US Inflation Reduction Act, T&E report January 2023, *https://www.transportenvironment.org/discover/a-european-response-to-us-inflation-reduction-act/*

[21] Commission Staff Working Document. Accompanying the document, Report from the Commission to the European Parliament and the Council. Progress on competitiveness of clean energy technologies. 1-Macroeconomic. SWD (2021) 307 final. October 2021. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD:2021:307:FIN#footnote114

[22] Entwicklung und Umsetzung eines Monitoringsystems zur Analyse der Akteursstruktur bei Freiflächen-Photovoltaik und der Windenergie an Land, https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-06-28_cc_49-2021_monitoringsystem_akteursstruktur_wind_pv.pdf

[23] *Commitments but no plans, T&E 2021 report, https://www.transportenvironment.org/wp-content/uploads/2021/08/202106_EV_Report-Final-1.pdf*

[24] A European Response to the US Inflation Reduction Act, T&E report January 2023, *https://www.transportenvironment.org/discover/a-european-response-to-us-inflation-reduction-act/*

- Europe has secured much investment: the continent is projected to produce up to a third of lithium-ion batteries globally by 2030 (from just a few % today)[25].

However, this investment will likely not proceed if the derogations are limited to 13.5 years only. A company is not likely to invest in building a battery cell production factory with the knowledge that they will have to close the factory in 13.5 years.

Even if this derogation is granted with a review clause, this may still not provide sufficient certainty for companies to invest in Europe because there is risk that the derogation may not be renewed and therefore prevent any further competition. This uncertainty is already diverting some investment from Europe and putting a high risk on the current investment in Europe, which could jeopardise the current set up of the European value chain. For this reason, the European Battery Association RECHARGE will propose an alternative approach to manage the PFAS emissions risk in a different way.

Figure 1 summarises the battery cell production sites in Europe that are in planning, under construction or partly already in operation[26]. These 45 sites represent over 56 billion Euros of investment and more than 43,000 jobs and provide the potential for Europe to become self-sufficient in battery cells as early as 2028 as an integrated value chain.

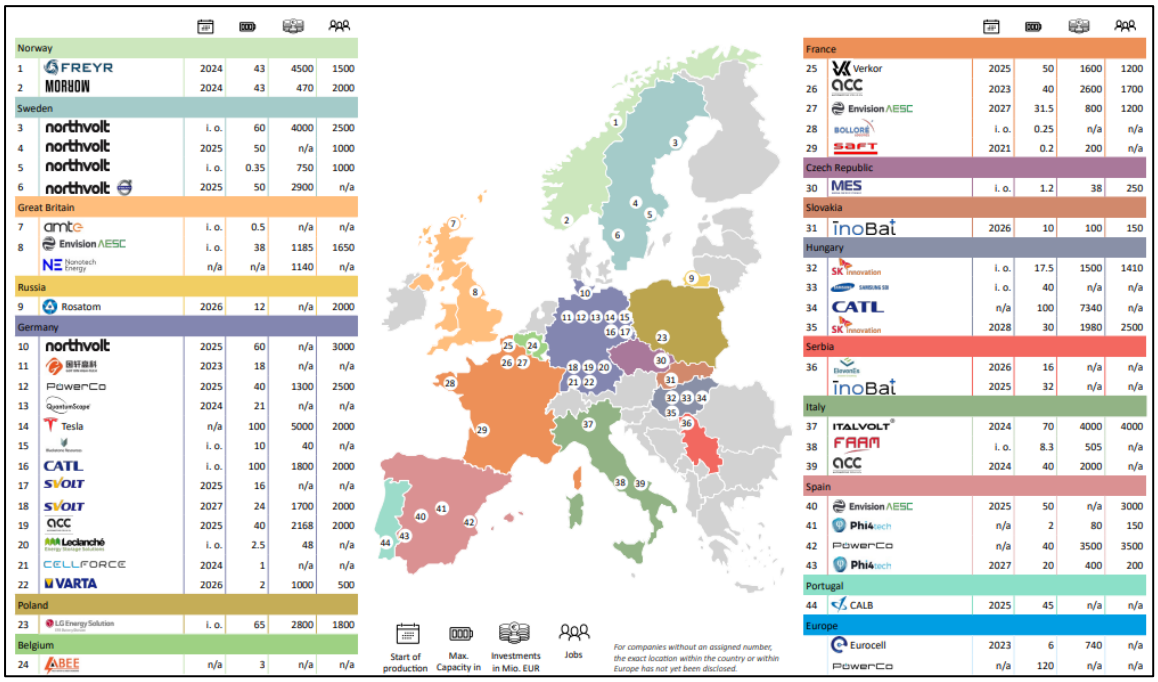

Figure 3 Battery cell production site in Europe

A PFAS restriction without a derogation for batteries, and a review clause, will stop these battery cell production sites operating in Europe.

[25] A European Response to the US Inflation Reduction Act, T&E report January 2023, https://www.transportenvironment.org/discover/a-european-response-to-us-inflation-reduction-act/

[26] Figures include EU Member States and European Economic Area countries – therefore Russia, UK & Serbia have not been included in our calculations. Figures obtained from IPCEI Market Analysis Q4 2022, https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/publications/2023-02-BZF_Kurzinfo_Marktanalyse_Q4_22-ENG.pdf.

EV batteries

Batteries are critical to the functioning of society to enable electric vehicles to replace sales of new combustion engine vehicles by 2035. On 29 June 2022, all climate ministers of the 27 EU member states agreed to the European Commission's proposal (part of the 'Fit for 55' package) to effectively ban the sale of new internal combustion vehicles by 2035 (through '[introducing] a 100% CO_2 emissions reduction target by 2035 for new cars and vans')[27]. Requiring new cars sold in the EU to emit zero CO_2 from 2035 would make it impossible to sell new internal-combustion engine cars. In 2026, the Commission will assess whether hybrid vehicles or CO_2-neutral fuels could comply with the goal with future technological developments. The Commission commented that it would keep an "open mind" but that at present, hybrids did not deliver sufficient emissions cuts and alternative fuels were prohibitively expensive.

Most EU Member States have also signed up to the COP26 declaration on accelerating the transition to 100% zero emission cars and vans[28]. All signatories support an accelerated transition to zero emission vehicles in line with achieving 100% of new car and van sales being zero emission in leading markets by 2035, and by making them accessible, affordable and sustainable in all regions by 2030.

These climate proposals aim to ensure the EU – the world's third-biggest greenhouse gas emitter – reaches its 2030 target of reducing net emissions by 55% from 1990 levels. Doing so will require governments and industries to invest heavily in electric vehicles.

A PFAS restriction without a derogation for batteries, and a review clause, will stop sales of new and second-hand electric vehicles in Europe.

Industrial batteries

In electricity generation, batteries enable grids to install more renewable energy capacity using solar and wind sources. One of the well-known shortcomings of solar and wind energy sources is their large variability in power generation - the sun does not always shine, and the wind does not always blow. Battery storage helps renewable generators reliably integrate with existing grids by storing the excess generation and by smoothing the energy distribution.

Batteries also help traditional suppliers manage the stability of energy distribution thanks to their unique ability to quickly absorb, store, and deliver electricity as needed. Among its many uses, batteries help operators regulate the frequency of the electrical current - an important aspect of electricity transmission – to help store electricity until transmission capacity is available and help maintain capacity reserves. Batteries also make isolated and off-grid installations viable and less dependent on diesel generators.

While there are many technologies used for utility-scale energy storage, rechargeable lithium batteries have become favoured in new installations due to their flexibility and scalability, and their declining costs. At the beginning of the 1990s, the storage capacity that is required to power a regular-sized house for a day would have cost about 75,000 Euro and the battery package would have weighed 111kg[29]. The same level of capacity can now be obtained at a cost of around 2,000 Euro from a 40kg, small backpack-sized cell.

[27] https://www.consilium.europa.eu/en/press/press-releases/2022/06/29/fit-for-55-council-reaches-general-approaches-relating-to-emissions-reductions-and-removals-and-their-social-impacts/
[28] https://www.gov.uk/government/publications/cop26-declaration-zero-emission-cars-and-vans/cop26-declaration-on-accelerating-the-transition-to-100-zero-emission-cars-and-vans
[29] https://www.economist.com/graphic-detail/2021/03/31/lithium-battery-costs-have-fallen-by-98-in-three-decades

Industrial batteries also include small primary lithium batteries, which are essential for applications that require long battery lifetimes (up to 25 years) or instant readiness after long standby periods (for applications such as pacemakers, defibrillators, emergency alarm systems, and remote IoT applications).

A PFAS restriction without a derogation for batteries, and a review clause, will inhibit the growth of renewable energy and stop the sales of life-saving equipment.

Portable batteries

The public in Europe rely on their electronic devices to continue to function in an emergency when a main power source is not available. For example, a long battery life is needed in communication devices such as smartphones, tablets and laptops so that in case of a health or safety incident, the device can continue to function to enable people at risk to continue to communicate effectively with the emergency response authorities. Batteries provide indispensable back-up power to these communication devices in case of a power cut.

Today's society is an information-rich world which is becoming more and more portable. Portable electronic devices including laptops, tablets, mobile phones, and wearable electronic devices are critical to support the rapid growth of information processing and sharing in society. Without batteries, these devices would not be portable and instead would require permanent connection to a fixed power source.

From VOIP to global telecom carriers, portable electronic devices enable people to travel the world and stay connected. To respond effectively to global pandemics such as COVID 19, remote workers and international businesses need to be able to utilize video calls and conference calls via the Internet to keep their businesses going without interruption. Portable electronic devices support increased productivity by enabling working from home opportunities that simply were not available previously. At the same time, more flexible working arrangements have enabled a larger cross-section of society to contribute their knowledge and skills into the workplace.

Portable electronic devices have enabled more people to access education opportunities. Online seminars allow people to learn in a faster, more convenient, and efficient fashion.

Portable electronic device help people to carry out complex tasks in a simpler, quicker manner. Smart bracelets and health apps enable people to monitor, analyse and alter personal health habits. Many hospital systems have online gateways that allow patients to obtain their medical records, or communicate with their physician online, nearly instantly. Batteries are indispensable to make these devices portable so that they can deliver these critical functions to society.

Significant financial costs can be expected to arise due to the lack of substitutes for PFAS in lithium-ion batteries:

1. Annual value of EU sales: In 2022, the computer hardware market in Europe generated a total revenue of over 60 billion euros, selling around 630 million units. Storage units made up the majority of volume at approximately 462 million units, followed by laptops and keyboards, both with approximately 42 and 40 million units sold, respectively.[30]
2. Indirect cost - European employment in the ICT sector: In 2022, more than 9 million persons worked as ICT specialists across the European Union (EU). The highest number (2.1 million) worked in Germany, which provided work to more than one-fifth

[30] Statista, 2023 see https://www.statista.com/forecasts/1256748/volume-segments-computer-hardware-europe

(22.6 %) of the EU's ICT workforce. France (1.2 million) had the second largest ICT workforce (13.0 % of the EU total), followed by Italy and Spain (both 0.9 million; 9.6 % and 9.4 % respectively).[31]

3. Cost to companies in the EU: In a survey conducted by the IDC (2010), 68 % of respondents confirmed that the battery lifetime on their notebook computers was not sufficient for their business needs, and over half stated that battery failures caused problems for their business. The most common problem was lost productivity, cited by 45 % of respondents, followed by lost/delayed sales (22 %) and loss of critical company data (17 %).
4. Material efficiency via optimized design: The yearly rate of estimated material saving if dedicated functionality for the optimization of the lifetime of batteries (a.1) were used ranges from around 2 360 to 5 400 tonnes (t) of different materials per year. About 450 t of cobalt, 100 t of lithium, 210 t of nickel and 730 t of copper could be saved every year.[32]
5. R&D, retooling, retesting, recertifying supply chain costs: not able to be estimated.
6. Cost to consumers & companies in the EU to repair/replace electronic devices on more frequent cycles: A Eurobarometer survey observed that, when a main failure occurs, 77 % of EU citizens would rather repair their goods than buy new ones, but ultimately have to replace or discard them because they are discouraged by the cost of repairs and the level of service provided (European Commission, 2014b). Viegand Maagøe and VITO (2017) reported a typical lifetime of 5 years for notebooks, 6 years for desktop computers. (Sources: Viegand Maagøe and VITO, 2017. Preparatory study on the Review of Regulation 617/2013 (Lot 3) — Computers and Computer Servers & Flash Eurobarometer 388 report of June 2014 entitled 'Attitudes of Europeans towards waste management and resource efficiency'.)
7. Impact of downtime to EU businesses when electronic devices fail: Data in the public domain tends to focus on the cost to businesses resulting from network outages rather than devices, but costs will vary according to the sector and size of the business but will include productivity losses, replacement costs, and lost sales.
8. Impact to employment: Approximately 45 battery cell production sites in Europe that are in planning, under construction or partly already in operation represent 56 billion Euros of investment and 43,000 jobs (PCEI Market Analysis Q4 2022, https://www.ipcei-batteries.eu/fileadmin/Images/accompanying-research/publications/2023-02- BZF_Kurzinfo_Marktanalyse_Q4_22-ENG.pdf). This will aid Europe to become self-sufficient in battery cells as early as 2028 as an integrated value chain. Without PFAS derogations for batteries, these battery production sites will stop operating in Europe.

A PFAS restriction without a derogation for batteries, and a review clause, will stop Europe from achieving Green Deal digitalisation objectives.

[31] Eurostat, 2023, ICT Specialists in Employment, https://ec.europa.eu/Eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment#Number_of_ICT_specialists
[32] Tsiropoulos, I., Tarvydas, D. and Lebedeva, N., Li-ion batteries for mobility and stationary storage applications, https://publications.jrc.ec.europa.eu/repository/handle/JRC113360

3. Coating materials

3.1. Anti-fingerprint coating

Name of PFAS substance(s): Fluoropolymers (e.g. PTFE), Perfluoropolyether (PFPE), Perfluoroalkoxy alkanes (PFA)

General summary on the application category

PFAS substances are widely used in anti-fingerprint coatings in various electronic products such as laptops, smartphones, keyboards and visual devices.

These coatings are used because they are chemically inert, easy to clean, and have excellent aging performance, abrasion resistance (due to the self-lubricating property of PFAS) and adhesion durability.

The anti-fingerprint coating creates a layer of water- and oil-resistant material with a water contact angle greater than 110º and oil contact angle greater than 80º, effectively preventing grease and various chemicals from sticking to the surface. The coating also allows easy removal of dust and dirt (from hand creams and tomato ketchup to alcohol and sunscreen) from the surface.

ChemSec has highlighted silicone alternatives, however during testing they have demonstrated more severe fouling as compared to PFAS coatings when tested with multiple substances, including artificial sweat, vegetable oil, coke and coffee etc., and poorer abrasion resistance and durability. They also exhibit a water contact angle of less than 100º meaning they are much harder to clean as compared to PFAS coatings.

The finger is often coated with sebum, an oily substance. The oil-phobic characteristics of PFAS coated on substrate can remove the sebum, and the touch feeling is smooth without sluggishness. However, if there is no PFAS coating, an oil-phobic coating, the sebum is adhered on the substrate. The sebum adhered on the substrate makes the sliding motion un-smooth. Silicone based coating has hydrophobic but not oil-phobic characteristics. The sebum is therefore kept on the silicone-based coating surface, making the sliding motion unsmooth.

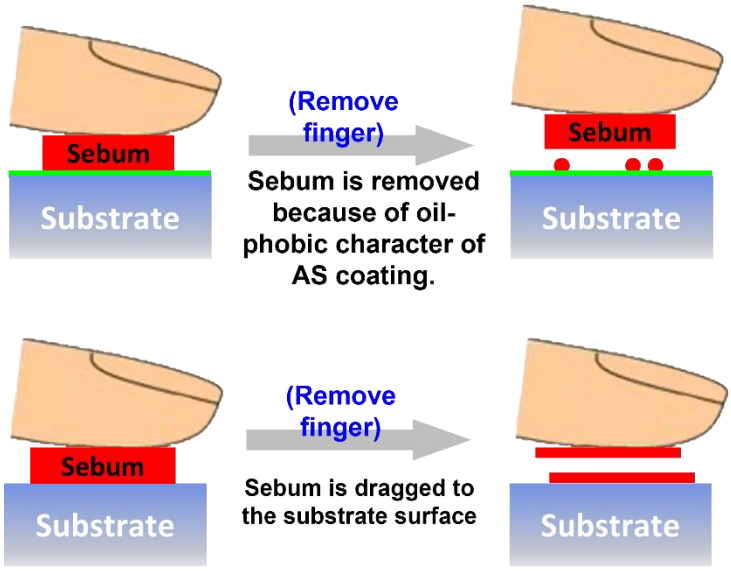

Figure 4 Oil-phobic characteristics of PFAS anti-fingerprint coating

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify/See confidential annex for details.

The key functionalities provided by PFAS for the relevant use[33]

1. Very low surface energy on the substrate surface to promote water and oil repellency (>=110° water contact angle; >=80° oil contact angle)
2. High chemical resistance, against water and oil-based materials
3. High abrasion resistance and low friction coefficient (< 0.3)
4. High adhesion durability
5. 100% visible light transmittance possible in <100 nm coating thicknesses

For which uses of PFAS is there no alternative?

Outlook: No alternative has yet been identified.

R&D activity: Some potential non-PFAS alternatives have been assessed - mainly Si-based materials, but also PU and chlorinated chemistries.[34]

Alternatives cannot match the performance of PFAS:

- Surface tension / energy of alternatives is not as low as PFAS. Alternatives are unable to achieve water contact angle >=110°, and oil contact angle >=80° which causes wetting of surface.
- The anti-fouling performance of alternatives is not as good as PFAS. Coatings based on PFAS exhibit much better easy-cleaning ability than Si-based coatings.
- Chemical stability and resistance of alternatives is not as good.
- Abrasion resistance of alternatives is not good, resulting in poor long-term durability [Supplier Survey 2023, OECD]
- Temperature stability/resistance of PFAS is superior, which can operate at >200 °C[35]
- Thicker coating may need to be applied for alternative [OECD]. Silica-based coatings such as silicone polymers can be used as alternatives to radiation curable coatings in electronics as they have similar properties and therefore can carry out similar function as PFASs used in this application. In electronics, however, PFAS can be applied in a thinner layer compared to non-PFAS alternatives - fluoropolymers are typically applied in a coating thickness of 1-2 µm (nano coating), whereas alternatives such as acrylic, PU and silicone are applied at >25 µm.[36]

Si-based alternatives may meet lower specifications for abrasion resistance, contact angle and anti-fouling tests, but these are not acceptable per industry and customer experience

[33] Source: Supplier Survey 2023
[34] Source: Supplier Survey 2023, Chemsec, OECD
[35] ChemSec (2023), Check Your Tech: A guide to PFAS in Electronics, https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fchemsec.org%2Fapp%2Fuploads%2F2023%2F04%2FExcel_ChemSec-Electronics-Guide.xlsx&wdOrigin=BROWSELINK
[36] Chemsec (2023)

requirements and will result in shorter product service life. In addition, silicone coating absorbs oil, is sticky, causes cross contamination and leads to adhesion loss of other components.[37]

Substitution:

- The time required to develop a new material that meets all the performance requirements is unknown. It is estimated to take at least 2 years for suppliers to study, screen and identify a potential substitute.
- Once a potential substitute is identified, it will take 1.5 years for material qualification, manufacturing process development and part level qualification (environmental aging simulation, adhesion duration, storage stability, easy cleaning performance).

Proposed derogation

Paragraph 2(c) shall apply from (**6.5 years** after entry into force) to **anti-fingerprint coatings** in electrical and electronic equipment. By [18 months before the derogations are due to expire] the Commission will review derogations in light of new scientific available information and information on alternative materials or processes and if appropriate modify this derogation accordingly.

3.2. Coating and paint for enhanced abrasion resistance in EEE

Name of PFAS substance(s) PTFE

General summary on the application category

Components inside devices can corrode or degrade when exposed to contaminants, moisture or wear. The degradation can reduce the electrical and mechanical performance of the device and cause device failure in some cases. Manufacturers use specialized paints/coatings to protect these sensitive components.

Fluoropolymers are used as additives/binders in paints because they confer protective properties on the paints such as durability, weatherability and resistance to corrosion and dirt pick up as well as acting as a barrier to UV deterioration and providing a soft feel 'texturizer' for some applications. Fluoropolymers commonly used in paints are primarily based on PVDF, PTFE, FEP, ETFE and FEVE. They impart excellent self-lubricating property, wear resistance, water, heat and chemical resistance and high-performance electrical insulation. These characteristics help extend the lifespan of components and improve their fire safety.

Product durability is a key focus of policy efforts as part of the Circular Electronics Initiative and has been a key feature in the review of Ecodesign Regulation 617/2013 (Lot 3) - Computers and Computer Services.

Si-based alternatives have been tested but have so far failed to meet performance and durability requirements.

[37] Chemsec (2023)

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify -

The key functionalities provided by PFAS for the relevant use[38]

1. Very low surface energy on the substrate surface to promote water and oil repellency (>=110° water contact angle; >=80° oil contact angle)
2. Excellent durability and abrasion resistance (also due to very low friction coefficient)
3. Wide temperature range and thermal stability (-30℃ -150℃)
4. High resistance to chemicals and compatibility with oxygen
5. Excellent adhesion durability

For which uses of PFAS is there no alternative?[39]

Outlook: No alternative has yet been identified.

R&D activity: Alternatives examined included PE waxes and Si-based solutions.

Alternatives cannot meet performance and durability requirements:

- Worse abrasion durability
- Worse chemical resistance
- Worse anti-fouling performance

Si-based alternatives may meet lower specifications for abrasion resistance, contact angle and anti-fouling tests, but these are not acceptable per industry and customer experience requirements and will result in shorter product service life. In addition, silicone absorbs oil, is sticky, causes cross contamination and leads to adhesion loss of other components.

Substitution:

- The time required to develop a new material that meets all the performance requirements is unknown. It is estimated to take at least 2 years for suppliers to study, screen and identify a potential substitute.
- Once a potential substitute is identified, it will take 1.5 years for material qualification, manufacturing process development and part level qualification (environmental aging simulation, adhesion duration, storage stability, easy cleaning performance).

Proposed derogation

Paragraph 2(c) shall apply from (**6.5 years** after entry into force) to **fluoropolymer coatings and paints for enhanced abrasion resistance** in electrical and electronic equipment. By [18 months before the derogations are due to expire] the Commission will review derogations in light of new scientific available information and information on alternative materials or processes and if appropriate modify this derogation accordingly.

[38] Source: Supplier Survey (2023)
[39] Source: Supplier Survey (2023)

3.3. Coating in connectors

Name of PFAS substance(s) Fluoropolymers

General summary on the application category

Plug-in connections are used wherever components or assemblies need to be connected temporarily. Electrical contacts have basically two main tasks: the possibility to mechanically separate an electrical connection and the transmission of electrical energy without losses in closed position. As they are used in a wide range of different environments, like heat or damp heat, the contact surface of the electrical contact has to meet various requirements.

The main function of this PFAS coating on the gold plated elements is to seal micro pores on the surface and prevent corrosion. Thin gold plating can be microscopically porous and corrosion would lead to increased contact resistance. For plastic parts, the PFAS anti-flux coating helps to ensure efficient soldering when performing surface mounting - limiting the flow of solder when being applied.

To date, no alternatives have been found.[40]

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify/See confidential annex.

The key functionalities provided by PFAS for the relevant use

1. Low wettability (through low surface tension / energy)
2. Sealing micro-sized holes offering effective corrosion protection

For which uses of PFAS is there no alternative?

Outlook: Potential alternatives all contain PFAS according to the supply chain. It is important to find a material that does not stick during the manufacturing process.

Substitution[41]:

- The time required to develop a new material that meets all the performance requirements is unknown. It is estimated to take at least 2 years for suppliers to study, screen and identify a potential substitute.
- Once a potential substitute is identified, typical duration of manufacturing process update and testing takes at least 20 months, depending on application and the required tooling investment.

[40] Supplier Survey (2023)
[41] Supplier Survey (2023)

Proposed derogation

Paragraph 2(c) shall apply from (**6.5 years** after entry into force) to **fluoropolymer coatings in connectors** in electrical and electronic equipment. By [18 months before the derogations are due to expire] the Commission will review derogations in light of new scientific available information and information on alternative materials or processes and if appropriate modify this derogation accordingly.

3.4. Optical isolation layers for display applications

Name of PFAS substance(s) Fluoropolymers (e.g. PTFE), Perfluoropolyether (PFPE)

General summary on the application category

PFAS-containing low optical loss and refractive index coatings and adhesives are used to preserve total internal reflection (TIR) of the light in advanced display applications like waveguides. Waveguides leverage specific optical properties of the material to guide wavelengths if sound, light or other radiational energy across the material. Basic examples would be optical fibers and magnetrons within microwaves. If the optical properties are not maintained then the light will not be effectively transferred across the material by either absorption or misdirection losses. Key requirements for effective transmissions are low optical loss (<0.5%), low RI (<1.35), ability to cure at ambient or low (<80C) temperatures, low moisture absorption, non-yellowing, PFAS-containing materials and high elongation at break. Currently, the PFAS-containing materials are the only HVM-compatible option available that can satisfy the required optical and mechanical properties of the coatings.

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to fully quantify, but we can elaborate on the expected emission points, mitigations in place, potential volumes.

Expected Volumes – The end use of this material will be used in EEE. Market acceptance will be a significant variable in determining the total number of products on the EU market. Each product would contain approximately 1 g of PFAS.
Manufacturing - Substance will be applied in a closed loop system that is under strictly controlled conditions.
Recovery - This material will be contained in EE and subject to WEEE. Expected 90% recovery/refurb/reuse of the product.

The key functionalities provided by PFAS for the relevant use

1. Low Refractive index (<1.35)
2. Low optical loss in visible region (<0.5% over 2 um)
3. Low moisture absorption
4. Good adhesion between various interfaces
5. Low modulus and high elongation at break to accommodate for CTE mismatch between layers

For which uses of PFAS is there no alternative?

Outlook:
Alternative commercially available materials like silicones are limited to RI of ~1.40 making them unsuitable for these applications. The high refractive index causes the light to deflect at a much greater angle thus distorting the projections to an indistinguishable state. There is active academic research in porous low RI materials, but these materials are brittle and suffer from high moisture absorption making them unsuitable for these applications as well. In recent years, the coatings industry has initiated the research and development of hollow nanoparticles matrix composite materials to achieve low RI (~1.36) and low temperature curable materials. These materials are in early stage R&D with long cycle times for development and currently suffer from high moisture absorption and delamination.

Substitution:

- The time required to develop a new material that meets all the performance requirements is unknown. It is estimated to take at least 4 years for suppliers to study, screen and identify a potential substitute.

- Once a potential substitute is identified, it will take 1.5 years for material qualification, manufacturing process development and part level qualification (environmental aging simulation, adhesion duration, storage stability, TIR performance).

Proposed derogation

Paragraph 2(c) shall apply from (**6.5 years** after entry into force) to **Optical Isolations Layers For Coatings**. By [18 months before the derogations are due to expire] the Commission will review derogations in light of new scientific available information and information on alternative materials or processes and if appropriate modify this derogation accordingly.

3.5. Coatings: Socio-economic impacts

The consequential economic (in euros) and social (e.g. jobs) impacts arising from any restriction of PFAS in respect to its use in coatings is difficult to quantify. However, significant financial costs can be expected to arise because of the inability to substitute.

While industry will face increased costs associated with conducting repairs in warranties and searching for alternatives, perhaps the greatest cost impact will be felt by businesses and consumers to replace electronic devices on more frequent cycles due to device failure and/or loss of consumer expected performance, and the impact to EU businesses as a result of downtime when products fail.

1. Annual value of EU sales: In 2022, the computer hardware market in Europe generated a total revenue of over 60 billion euros, selling around 630 million units. Storage units

made up the majority of volume at approximately 462 million units, followed by laptops and keyboards, both with approximately 42 and 40 million units sold, respectively.[42]

2. Cost to companies/consumers in the EU to repair/replace electronic devices on more frequent cycles: A Eurobarometer survey observed that, when a main failure occurs, 77 % of EU citizens would rather repair their goods than buy new ones, but ultimately have to replace or discard them because they are discouraged by the cost of repairs and the level of service provided (European Commission, 2014b). Viegand Maagøe and VITO (2017) reported a typical lifetime of 5 years for notebooks, 6 years for desktop computers.[43]
3. Impact of downtime to EU businesses when electronic devices fail: Data in the public domain tends to focus on the cost to businesses resulting from network outages rather than devices, but costs will vary according to the sector and size of the business but will include productivity losses, replacement costs, and lost sales.
4. Total sector agnostic annual savings through extended component lifetime: Fluoropolymer coatings, linings and components prevent corrosion in demanding environments. Each percent reduction in corrosion is estimated to deliver savings of some €150m per year across Europe. Amongst other benefits, they support savings in maintenance through increased component lifetime. Consultation suggested their use effectively doubled the lifetime of equipment, potentially yielding savings in the order of €100m annually. (Source, FPG, Plastic Europe, 2017 https://fluoropolymers.plasticseurope.org/application/files/7816/1167/4026/Final_SEA_Fluoropolymers_summary2017_3.pdf)
5. R&D, retooling, retesting, recertifying supply chain costs: not able to be estimated.

[42] Statista (2023), https://www.statista.com/forecasts/1256748/volume-segments-computer-hardware-europe
[43] Viegand Maagøe and Vlaamse Instelling voor Technologisch Onderzoek NV (VITO) (2017) Preparatory study on the Review of Ecodesign Regulation 617/2013 (Lot 3) - Computers and Computer servers. Task 7 Report: Policy Measures and Scenario Analysis, https://computerregulationreview.eu/sites/computerregulationreview.eu/files/Preparatory%20study%20on%20review%20computer%20regulation%20-%20Task%207%20VM%2019072018.pdf

4. Anti-dripping agents

Name of PFAS substance(s) PTFE

General summary on the application category

Flame retardant polycarbonate (PC) resins and alloys, such as PC/ABS used in thin-wall (thickness <1.0 mm) electronics applications play a critical role in consumer safety and require the use of PTFE as an anti-drip additive. These flame-retardant polycarbonate resin formulations are used where product safety (mitigated risk of flame/fire and/or electrical shock) is of utmost importance.

Thin-walled parts reduce the amount of plastic used and therefore the amount of plastic waste produced during the manufacturing process as well as at the electronic devices' end of life. Before these tough thin-wall flame retardant polycarbonates were available, typical wall thicknesses in consumer electronics were 2-3 mm, which in comparison can lead to a 100% to 200% increase in resource consumption and solid waste generation, depending upon the electronic application design requirements. As the devices are subsequently lighter, have resulted in reduced scope 3 emissions (category 4- upstream transportation and distribution, and category 9 downstream transportation and distribution)[44]

Our justification for requesting derogation of PTFE as anti-drip agent in flame retardant polycarbonate compounds comprises two elements:

- there are no alternatives to polycarbonate that provide adequate impact resistance and ductility for thin wall (<1.0 mm) applications in electronic products
- in order to ensure that the polycarbonate thin wall has adequate flame retardancy, it is essential to use PTFE as the anti-drip agent.

Alongside many unique properties, polycarbonate is an inherently tough material which provides device integrity during and after an impact event, so that the electronic device can continue to function, and does not produce an electrical hazard (short circuit, shock hazard) or a fire hazard. There are no alternative engineering plastics available today that provide the necessary combination of impact resistance, ductility, and flammability properties for thin-walled (<1 mm) electronic device parts. These properties are crucial to:

- provide a durable product that does not break during normal use, including drops and other foreseeable events,
- ensure safety by avoiding exposure of life circuitry, and
- meet EU regulatory requirements on the safety of electrical device.

The next best material is polyphenylsulfone (PPSU) which has almost half the ductility. By extension, we can expect that electronic products with thin walls (<1.0 mm) made from PPSU would be twice as fragile compared to the same products made with polycarbonate. Increased fragility means increased risk that the device may break after an impact event, which may result in electrical hazard (short circuit, shock hazard) or fire hazard.

[44] RCOM Ref 4009, RCOM Ref 4407

To ensure that thin-walled polycarbonate resins and alloys have adequate flame retardancy, it is essential to use PTFE as the anti-drip agent. PTFE, in combination with flame retardant additives, increases the ignition resistance of the polycarbonate thereby lowering the probability of a fire event. If a flame event does occur, the unique properties of PTFE help prevent flames from spreading and allow individuals more time to escape a fire.

Extensive research in the plastic industry has not found any alternatives that provide adequate flammability performance for thin-walled polycarbonate while also maintaining adequate impact resistance and ductility. Plastics manufacturers have carried out in-house experiments to investigate whether they could develop alternative additives that could be used instead of PTFE. None of the alternatives that were tested were able to provide adequate flame-retardant properties without significantly degrading impact resistance or other mechanical properties.[45]

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

No PTFE is released from parts manufactured from thin-walled polycarbonates during their use phase.[46] At end-of-life, when these articles containing 0.1-0.5 weight% of PTFE in the polycarbonate matrix will eventually enter the waste stage, the amount of PFAS emissions depends on the waste (pre-) treatment method, e.g., recycling/re-use, landfilling and incineration. However, PTFE is a fluoropolymer that is not water soluble and therefore does not present the specific hazards which are found with non-polymeric PFAS. PTFE is chemically, thermally, and biologically stable and therefore is not expected to transform to dispersive nonpolymeric PFAS when disposed of in a landfill. A recent study[47] presented results from OECD guideline biodegradation studies demonstrating that PTFE is stable and does not degrade to non-polymeric PFAS under environmentally relevant conditions. Further, PTFE meets the criteria to be considered a Polymer of Low Concern, PLC, which has negligible leachables, unreacted monomers, and oligomers most likely destroyed in use processing and would therefore not be expected to significantly contribute to landfill leachate.

The key functionalities provided by PFAS for the relevant use[48]

Nearly all electronic devices have an inherent risk of fire and a risk of shock. Product safety standards use material fire resistance and electrical insulation requirements as two critical safety elements to help mitigate these risks. For fire resistance, there are several common industry test standards that require materials to resist ignition, burning, and the dripping of flaming particles. One common standard is "*UL 94, the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances*" which is now harmonized with the IEC 60707, 60695-11-10 and 60695-11-20 standards and the ISO 9772 and 9773 standards that are used to demonstrate compliance to flame retardant requirements in the EU. There are 6 flame classifications of materials that are used in enclosures, structural parts and electrical insulators in electrical devices: HB, V-2, V-1, V-0, 5VA and 5VB. The higher ratings – V-1, V-0, 5VA and 5VB - all require that samples do not drip flaming particles.

Since polycarbonate is designed to be shaped/flowed by heat, direct flame application can lead to melting and dripping of the polycarbonate before or during ignition. Any flaming melting/dripping has the chance of spreading flaming material beyond the initial ignition event and is almost always more pronounced in thinner rather than thicker walls. PTFE is the only viable additive for polycarbonate resins used in thin walls that can inhibit dripping **and** retain

[45] RCOM Ref 4481
[46] RCOM Ref. 4044
[47] Stephen H. Korzeniowski et al. (2022), A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers, Integrated Environmental Assessment and Management Vol. 19 Issue 2, https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4646#pane-pcw-references
[48] RCOM Ref 4009, RCOM Ref 4407

all the impact resistance and ductility properties which are essential for product safety and compliance with regulatory requirements.

During melting and shaping of the polycarbonate into injection molded parts, the PTFE does not melt and instead undergoes a physical form change from being semi-spherical particles to highly elongated fibrils. These long fibrils form an entangled network inside the polycarbonate resin matrix. During a flame event, this network of PTFE fibrils does not burn/ignite and instead helps promote char formation and provides much higher melt strength to the thin polycarbonate wall. PTFE as an anti-drip agent is typically used in the range of 0.1-0.5% by weight of the total polycarbonate resin formulation.

For which uses of PFAS is there no alternative?

Outlook: No alternative has yet been identified.

R&D activity: Various flame-retardant materials have been examined as potential alternatives to polycarbonate resins, including PP, Nylon, PPE/PS, Polyetherimide, PPSU, and PEEK.

Why there are no alternatives to polycarbonate resins: Toughness

In addition to flame resistance, it is essential for product safety that thin plastic walls have adequate toughness to

- provide a durable product that does not break during normal use, including drops and other foreseeable events
- ensure safety by avoiding exposure of live circuitry, and
- meet EU regulatory requirements of the electrical device.

Toughness is comprised of a combination of two physical properties: impact resistance and ductility. Impact resistance is the material's *ability to absorb shock or impact energy without breaking*. Ductility is the material's ability to stretch without breaking.

A material's impact resistance and ductility can be measured using Notched Izod Impact (NII) and Tensile Elongation (TE). These techniques measure the amount of energy a material can absorb during impact and the percentage amount the material will stretch before breaking in controlled laboratory settings, following standardized test methods (e.g., ASTM D256[49]/ ISO 180[50] for NII and ASTM D639[51]/ISO 527[52] for TE). The higher the impact resistance and the ductility, the tougher the material is and the more resistant it is to cracking or breaking.

As highlighted in Table 1 polycarbonate resin formulations provide unmatched impact resistance and ductility in the afore-mentioned tests compared to other engineering plastics, while also providing the required flame resistance, as measured by the ability to pass UL94 V0 flame testing at less than 1.0 mm thickness. The other engineering plastics in the below table were selected, based on our technical expertise, as most likely to represent viable alternatives to polycarbonate blends. However, as described below, none of these other thermoplastics represent viable alternatives to polycarbonate based on our research.

[49] Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics (astm.org)
[50] ISO 180:2019 - Plastics — Determination of Izod impact strength
[51] Standard Test Method for Tensile Properties of Plastics (astm.org)
[52] ISO 527-1:2019 - Plastics — Determination of tensile properties — Part 1: General principles

Material (non-reinforced)	Property Comparsion			
	Property	**Flame Resistance**	**Impact/Crack Resistance**	**Ductility**
		Passes UL94 V-0 @<1.0 mm?	Notched Izod Impact, % of Reference	Elongation @Break, % of Reference
	Polycarbonate Blend	☑	100% (Ref)	100% (Ref)
	Nylon	☑	4% (96% decrease)	4% (96% decrease)
	PPE/PS	☑	12% (88% decrease)	14% (86% decrease)
	Polyetherimide	☑	4% (96% decrease)	55% (45% decrease)
	PPSU	☑	83% (17% decrease)	55% (45% decrease)
	PEEK	☒	11% (89% decrease)	46% (54% decrease)
	Polypropylene	☒	4% (96% decrease)	120% (20% increase)

Table 2 Flame resistance, impact resistance and ductility of engineering plastics compared to polycarbonate

As can be seen in Table 1, several materials can achieve similar flame resistance to the polycarbonate, however none of these materials have a comparable combination of both impact resistance and ductility (hence, overall toughness).

Why there are no alternatives to PTFE for thin wall polycarbonate

There are several strategies that can be employed to increase resistance to flame dripping by increasing the melt strength or the stiffness of the material with either viscosity enhancers or mechanical fillers. However, Table 2 highlights that none of these strategies can provide the necessary flammability performance for thin-walled polycarbonate while also maintaining adequate impact resistance and ductility.

Highly branched/high viscosity polycarbonate can increase the melt strength and reduce flame dripping. However, this results in a significant reduction in impact resistance and ductility by 86% and 56% respectively and does not provide adequate overall flammability performance at less than 1.0 mm wall thicknesses.

Glass fiber or other inorganic fillers (Clay, Talc, Carbon Fiber) can be added to increase the stiffness of the material and reduce flame dripping. However, these additives must be used at relatively high loadings (20-50% or more by weight) to have a significant effect on flame dripping properties, and these high loadings cause a dramatic decrease in the ductility and impact resistance of the material. Glass, Talc and Clay fillers, at 20 weight % loading

significantly reduce the impact resistance and ductility by 84% and 96% respectively (and these properties will continue to deteriorate as filler loading increases), and do not provide adequate overall flammability performance at less than 1.0 mm wall thicknesses. Carbon fiber does provide adequate overall flammability performance at less than 1.0 mm wall thicknesses but significantly reduces the impact resistance and ductility by 90% and 99% respectively.

Property Comparison in PC				
PTFE Replacement	**Property**	**Flame Resistance**	**Impact/Crack Resistance**	**Ductility**
		Passes UL94 V-0 @<1.0 mm?	Notched Izod Impact, % of Reference	Elongation @Break, % of Reference
	PTFE	☑	100% (Ref)	100% (Ref)
	Branched/High Viscosity Resin	☒	14% (86% decrease)	44% (56% decrease)
	Mineral (Glass, Talc, Clay)	☒	16% (84% decrease)	4% (96% decrease)
	Carbon Fiber	☑	10% (90% decrease)	1% (99% decrease)

Table 3 Flame resistance, impact resistance and ductility of alternative anti-drip agents compared to PTFE in polycarbonate

As can be seen in the table, only one alternative approach to PTFE (carbon fiber) can achieve adequate overall flammability performance, however the significant reduction in impact resistance and ductility does not allow it to meet product safety requirements and so this approach cannot be used in design and manufacture of consumer electronics.

Substitution:

There are no alternatives to PTFE available today for thin-wall flame retardant polycarbonate resins. A wide range of potential alternatives have already been tested and found to fail to provide the necessary properties. A new round of extensive, fundamental laboratory research will be needed to attempt to identify a completely new material, unknown today, that may potentially be developed into an alternative to PTFE. It is estimated to take up to 8 years for this basic research.

If a new alternative material is identified it would take several more years to test, qualify, certify, and start manufacturing parts from this replacement material. Companies may need to make changes to their manufacturing equipment and processes to use the new material in their injection molding lines. These changes to manufacturing equipment and processes may be significant and require extensive time and capital investment.

Product requalification is a very time-consuming exercise which will require extensive resources over many years. The completion of this task will require sufficient test house capacity and transition time to requalify all existing thin-wall flame retardant polycarbonate

resin parts in products which are used in Europe for safety and performance. For a company with a wide range of existing product designs, we estimate it could take up to 5 years to carry out the necessary manufacturing equipment changes and product re-qualifications.

Proposed derogation

Paragraph 2(c) shall apply from (**13.5** years after entry into force) to PTFE used as **anti-dripping for polycarbonate resins and alloys (includes thermoplastics, such as Polycarbonates (PC), Polyvinyl Chloride (PVC), Polyamides, Acrylonitrile Butadiene Styrene (ABS), Polycarbonates (PC) and Acrylonitrile Butadiene Styrene (ABS) blend, Polypropylenes (PP), Thermoplastic Polyurethane (TPU), Polyethylenes (PE), Polyesters**.) **used for thin-walled parts** in electrical and electronic equipment.

4.1. Anti-dripping agents - socio-economic impacts

Statistics from several European countries reveal that electrical equipment account for 25 - 30% of all domestic fires, estimated in 273,000 fires per year. Fires can be generated by devices connected to the mains power, or battery powered devices. Lithium-ion batteries, in a fault condition, are also capable of overheating leading to ignition and subsequent explosion.

Flame retardancy has been proven to work and continues to be a powerful tool in the overall efforts to prevent fire related injuries and save lives. One of the most important benefits of flame retardancy in product design is they can stop small ignition events from turning into larger fires. Even if ignited material with flame retardancy also delay the spread of fire to give people sufficient time to escape. For example in the EU, due to the introduction of increased fire safety standards — the number of fire victims fell by more than 48% in France from 1982 to 2012, and by 56% in the UK from 1982 to 2013. Overall Europe has achieved substantial improvements in fire safety, with fire fatalities dropping by 65% over the last 30 years[53]. Since 2017, nearly different 500 types of electronic products have been recalled, withdrawn, or banned from sale in the EU due to fire hazards[54].

Other materials and components used in electronics are insufficient to prevent or delay the spread of fire from electronics. For example, protective components within electronics can reduce but not eliminate the risk of fire from electrical malfunction/failures. For example, a thermal fuse in a motor operated appliance will offer protection against an abnormal overload condition but it will not protect against other component failures like overheated power switches, connectors, wiring etc.

Another example is current-limiting components such as circuit breakers that are triggered by current rather than voltage. Once they are triggered, current limiting devices restrict power from reaching the equipment being protected without having to dissipate that power as heat. Therefore, there is virtually no limit to the amount of energy that they can handle. However, current-limiting devices do not generally respond fast enough to protect equipment from fast

[53] Modern building alliance Europe: Fire Death Rate Trends: An International perspective
[54] Safety Gate: the EU rapid alert system for dangerous non-food products

transient overvoltage's generated by lightning or electrostatic discharge which can lead to a flashover/arcing.

It is therefore essential to continue to guarantee the availability of PTFE and flame-retardant polycarbonate for the safety of electrical equipment on the European market until an effective and safe alternative can be found.

The consequential economic (in euros) and social (e.g. jobs) impacts arising from any restriction of PFAS in respect to its use as anti-drip additive in polycarbonate plastics is difficult to quantify. However, significant financial costs can be expected to arise.

1. **Annual value of EU sales**: In 2022, the computer hardware market in Europe generated a total revenue of over 60 billion euros, selling around 630 million units. Storage units made up the majority of volume at approximately 462 million units, followed by laptops and keyboards, both with approximately 42 and 40 million units sold, respectively.[55]
2. **Indirect cost - European employment in the ICT sector**: In 2022, more than 9 million persons worked as ICT specialists across the European Union (EU). The highest number (2.1 million) worked in Germany, which provided work to more than one-fifth (22.6 %) of the EU's ICT workforce. France (1.2 million) had the second largest ICT workforce (13.0 % of the EU total), followed by Italy and Spain (both 0.9 million; 9.6 % and 9.4 % respectively).[56]
3. **R&D, retooling, retesting, recertifying supply chain costs:** not able to be estimated.
4. **Cost to companies/consumers in the EU to repair/replace electronic devices on more frequent cycles**: A Eurobarometer survey observed that, when a main failure occurs, 77 % of EU citizens would rather repair their goods than buy new ones, but ultimately have to replace or discard them because they are discouraged by the cost of repairs and the level of service provided (European Commission, 2014b). Viegand Maagøe and VITO (2017) reported a typical lifetime of 5 years for notebooks, 6 years for desktop computers.[57]
5. **Impact of downtime to EU businesses when electronic devices fail**: Data in the public domain tends to focus on the cost to businesses resulting from network outages rather than devices, but costs will vary according to the sector and size of the business but will include productivity losses, replacement costs, and lost sales.

[55] Statista, 2023, https://www.statista.com/forecasts/1256748/volume-segments-computer-hardware-europe
[56] Eurostat, 2023, ICT Specialists in Employment, https://ec.europa.eu/Eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment#Number_of_ICT_specialists
[57] Viegand Maagøe and Vlaamse Instelling voor Technologisch Onderzoek NV (VITO) (2017) Preparatory study on the Review of Ecodesign Regulation 617/2013 (Lot 3) - Computers and Computer servers. Task 7 Report: Policy Measures and Scenario Analysis, https://computerregulationreview.eu/sites/computerregulationreview.eu/files/Preparatory%20study%20on%20review%20computer%20regulation%20-%20Task%207%20VM%2019072018.pdf

5. Cables/Connectors

General summary on the application category

A wide variety of materials is available as insulation and jacket for cables and connectors. Many types of plastics, rubbers and fluoropolymers are used in different applications. Fluoropolymers (PTFE, FEP, PVDF and PFA) are only chosen when other materials cannot meet the specific requirements on dielectric properties, flame and heat resistance, chemical inertness and/or durability. They are predominantly used in Direct Current (DC) cables and coaxial cables, but fluoropolymers can also be required for other cable types in demanding applications.

A DC cable is an electrical connector for supplying direct current power to electronic devices like computers and laptops.

Coaxial cables are used to carry high-frequency electrical signals. They are used in the electronics sector for the transmission of data - coaxial cables allow for high bandwidth and to transfer data over shorter distances in typically commercial and consumer settings. They differ from other shielded cables because the dimensions of the cable and connectors are controlled to give precise, constant conductor spacing, which is needed for it to function efficiently as a transmission line. Coaxial cables work by carrying data in the center conductor, while the surrounding layers of shielding perform to prevent harmful radiation while minimizing signal loss (also called signal attenuation). The first layer, called the dielectric, provides distance between the core conductor and the outer layers, as well as some insulation.

A discrete wire is a wire with a single conductor that terminates on one connector contact. When discrete wires are used to make cable assemblies, it is known as a discrete cable assembly. Discrete cables are commonly used for power transfer in the cable circuit design when the transmission current is higher within the same usable space in the device.

The uses of fluoropolymers (PTFE, FEP and PFA) are essential to the functioning of several types and/or uses of cables. PTFE, FEP and PFA are robust fluoropolymer materials that are used to insulate cables to improve performance for demanding applications. They have superb flame-retardant properties: no additional flame retardants are needed (reduces the use of halogenated flame retardants), they have high melting points and low rates of heat release and low smoke generation.

For coaxial cables with a diameter exceeding a quarter inch / 6.3mm alternative materials such as polyethylene foam can be used for certain applications. The minimum diameter relates to a minimum thickness of the dielectric material (reducing radio frequency signal losses to an acceptable level). This material has a much lower flammability rating which is acceptable only in specific applications.

Fluoropolymers also have excellent electrical properties (which means very low losses when transmitting high signals) and the widest temperature range of any plastic material – being able to withstand everything from -200ºC up to +260ºC and even up to +400ºC for a short length of time, which means they can transmit high power and withstand the high soldering temperature. Furthermore, they are highly resistant to sunlight, and therefore unlikely to degrade even in outdoor conditions. They provide excellent resistance to oils and other chemicals and UV light. They have superior mechanical flexibility – no plasticizers are needed (reduces the use of ortho-phthalates) and have the lowest coefficient of friction of any solid materials. Fluoropolymers are hydrophobic and resistant to hydrolysis; the typical properties

and dimensional stability remain unchanged even after long immersion in water which is good for cables/connectors for outdoor use.

There are no other chemicals that can provide all of these critical properties in combination in a standalone substance for cables/connectors. The uses of fluoropolymers in cables and connectors also enhance the product durability which is a key focus of policy efforts as part of the Circular Electronics Initiative and has been a key feature in the review of Ecodesign Regulation 617/2013 (Lot 3) - Computers and Computer Services.

Alternatives highlighted by ChemSec and by the Dossier Submitter

Analysis by ChemSec highlighted a high degree of uncertainty on whether alternatives were available.[58] This has been corroborated through extensive supplier engagement. No alternatives have yet been found that meet all the properties offered by these PFAS substances in cables and connectors.

The Dossier Submitters proposed alternatives for wire insulation. These non-PFAS alternatives are PEEK, PC and EDPM. A review was conducted to ascertain their feasibility as viable non-PFAS alternatives, focusing upon several prominent properties.

Dielectric Constant

Most fluoropolymers have a dielectric constant of ~ 2.0.[59] This is extremely critical as the size of electronic devices continues to shrink, which introduces new obstacles such as signal crosstalk, power consumption and time delays, as a result, fluoropolymers with low dielectric constants are needed to achieve faster and stable signal transmission.[60] Such dielectric characteristics are the result of the fluoropolymers' symmetrical molecular structure $(C_2F_4)n$ and the short distance between the carbon and fluorine[61].

The three proposed non-PFAS alternatives have much higher dielectric constants ranging from 2.7 – 4.5[62], which will result in much slower and unstable signal transmission. This will greatly affect the functioning, safety and quality of the electronic product for which these cables/connectors are utilised. Thicker insulation might solve this problem, but not in all applications there is sufficient space. Consequently, on this critical property alone, none of the proposed non-PFAS alternatives are suitable to replace PFAS for all cable applications.

Dissipation Factor

The dissipation factor can also be used to assess the characteristics or quality of an insulating material in applications such as cables, connectors, terminations, joints etc. The lower the value, the better the dissipation factor. Fluoropolymers have a low value of 2.0[63] which provides a highly efficient insulator. EPDM also performs well with this quality with a dissipation factor of 2.5[64], however, the other proposed non-PFAS alternatives PC and PEEK

[58] ChemSec (2023), Check Your Tech: A guide to PFAS in Electronics, https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fchemsec.org%2Fapp%2Fuploads%2F2023%2F04%2FExcel_ChemSec-Electronics-Guide.xlsx&wdOrigin=BROWSELINK

[59] Matweb (2023), Material Property Data, viewed 14 June 2023, < https://www.matweb.com/>

[60] Dong, J., Sang, X., Yin, W. and Chen, X. (2023) Preparation of fluorinated epoxy-phthalonitrile resins with excellent thermal stability and low dielectric constant. Journal of Applied Polymer Science, 140, p. 1-9

[61] Daikin 2023, Fluoropolymers Selection Guide, viewed 13 June 2023, https://www.daikinchemicals.com/solutions/products/fluoropolymers.html

[62] Matweb (2023); Gunasekaran, S., Natarajan, R.K., Kala, A. and Jagannathan, R. (2008) Dielectric studies of some rubber materials at microwave frequencies. Indian Journal of Pure and Applied Physics, 46, p. 733-737.

[63] Omnexus 2023, The Material Selection Platform, viewed 14 June 2023, https://omnexus.specialchem.com/

[64] Thorne & Derrick 2023, Properties of EPDM & Silicone Rubbers, viewed 13 June 2023, https://www.powerandcables.com/euromold-connectors-properties-performance-40-years-of-market-leadership

have dissipation factors of 9 and 30[65] respectively which are not best suited for cables/connectors.

Coefficient of Friction

Fluoropolymers have a Coefficient of Friction (COF) in the range of 0.02 - 0.08[66] which are effectively the lowest of any known solid material. Such properties have proven to be invaluable to the electronics industry in providing sustained durability. PC has the closest COF with a range of 0.05-0.18[67] to that of the fluoropolymers. PEEK has higher values of 0.15-0.40[68] while EPDM has very high values of 1.36 - 2.76[69] which are not suitable for cables/connectors.

Flame Retardancy

In terms of flame retardancy, a primary safety function, fluoropolymers are unique with their extremely high Limiting Oxygen Index (LOI) of ~95%[70] which inherently means they are non-flammable. The proposed alternatives have LOI values ranging from 19.5 - 24[71]. Taking EPDM with the lowest LOI value of 19.5, implies that it is a highly flammable substance that restricts its further application and development particularly within the electronics industry[72]. PC and PEEK also have low LOI values which would require flame retardant additives to be employed. However, the "Regulatory Strategy for Flame Retardants" published by the European Chemicals Agency in March 2023, which stated that "the substances in scope of this strategy are in principle all flame retardants.", places a very high degree of uncertainty on the future availability of flame retardants that would be required for the non-PFAS alternatives proposed by the Dossier Submitters.

In essence, the proposed non-PFAS alternatives have some of the necessary properties required for use in cables/connectors. However, they all have inappropriate characteristics that would require in some cases, the addition of supplemental chemical substances to render them functional which are also on a roadmap to be regulated under the REACH regulation. Others such as EPDM with its flammability properties precludes them on safety grounds from undertaking a meaningful function with cables/connectors.

Non-PFAS Alternatives Identified Through Research

Focusing upon research into non-PFAS alternatives has required an extensive literature review to determine what if any non-PFAS alternatives are being considered for cables and. The on-line library search engine utilised for this review was Summon™.

[65] Omnexus 2023, The Material Selection Platform, viewed 14 June 2023, https://omnexus.specialchem.com/
[66] Matweb (2023); Gunasekaran, S., Natarajan, R.K., Kala, A. and Jagannathan, R. (2008) Dielectric studies of some rubber materials at microwave frequencies. Indian Journal of Pure and Applied Physics, 46, p. 733-737.
[67] Matweb (2023)
[68] Matweb (2023)
[69] Mukhopadhyay, A. (2014) Friction and wear characteristics of indigenous 'EPDM' rubber under dry sliding condition. ARME, 3, (2), p. 1-25.
[70] Omnexus (2023)
[71] Omnexus (2023)
[72] Tang, G., Hu, Y. and Song, L. (2013) Study on the flammability and thermal degradation of a novel intumescent flame-retardant EPDM composite. Procedia Engineering, 62, p. 371-376

Error! Reference source not found.4 illustrates the keywords/phrases utilised in an effort to comprehend what research into non-PFAS alternatives for cables and connectors taken place or indeed is still on-going.

Keyword or Phrase	# of Results	Results of Relevance to PFAS in Cables/Connectors/Capacitors
PFAS	68,857	Reviewed the first 1,000 results. None of them were relevant.
PFAS in electronics	1,791	None
Non PFAS alternatives in electronics	19	None
PFAS alternatives in electronics	78	None
Fluoropolymer alternatives in electronics	84	Most of the results focused upon fuel cells, membrane materials for alternative energy and sustainability applications. None were relevant for cables, connectors and capacitors.
PFAS in electrical cables	188	There were some relevant results, but the papers emphasised the benefits of fluoropolymers in cable products.
Fluoropolymer alternatives in electrical cables	10	None
PFAS in electrical connectors	8	None
Fluoropolymer alternatives in electrical connectors	0	None

Table 4 PFAS literature review for non-PFAS alternatives in cables, connectors and capacitors

Based upon the findings in Table 4, it is apparent that if there is on-going research into non-PFAS alternatives for cables and connectors, none of it is finding its way into the public domain. This scenario is more than likely a result of the lack of research into these electronic components/products.

Waste

Latest data from Eurostat showed that the recycling rate for separated WEEE stood at 84.5% in 2020.[73] Due to the likely presence of POPs, antimony trioxide and plasticizers in cables, they attract a hazardous waste code. Indeed, since the introduction of more stringent requirements in respect to POPs, any WEEE plastic waste suspected of containing POPs are either burnt in high temperature incineration (i.e. cement kilns) or disposed of in hazardous waste landfills.

In the next three sections 5.1 – 5.3 examples are given of cables and connectors for which there is no PFAS-free alternative for all uses. These examples are not exhaustive. Other types of cables may also require the use of PFAS in demanding applications/environments.

[73] https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework

5.1. DC cable insulation

Name of PFAS substance(s) PTFE, FEP and other fluoropolymers

CAS Number(s) 9002-84-0, 25067-11-2, 25190-89-0 and more

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify/See confidential annex for details.

The key functionalities provided by PFAS for the use in DC cable insulation

1. High temperature stability

   Melting point of FEP is 285°C and PTFE is 327°C. These are significantly higher than potential alternative materials[74]

2. High flame retardant ratings

   The UL flammability ratings of FEP and PTFE are both V-0. This is essential to ensuring the fire safety of the product. Alternative materials typically have lower flammability ratings and therefore could compromise the safety of the product.[75]

3. High chemical resistance[76]: Fluoropolymers (e.g. FEP or PTFE) are inert to acid and base. This is a key characteristic of fluoropolymers to ensure safety and well protection on the conductor inside.

4. High mechanical flexibility (see details below)[77]

For which uses of PFAS is there no alternative?

Outlook: Analysis by ChemSec highlighted a high degree of uncertainty whether alternatives were available. This has been corroborated through extensive supplier engagement. No alternatives have yet been found that meet all properties offered by these two substances in this use.

*R&D activity***:** To date, materials that have been examined include TPE, PVC as well as polyolefins, such as PE and PP.

- **PE, PP and TPE have relatively low melting points compared to PFAS and cannot meet the high temperature stability requirement for certain applications.**
  The melting point for the insulation material is key to DC cables. This is particularly crucial due to the soldering/welding process involved in the manufacturing process. When soldering, temperatures around 300°C are transmitted to the insulation through the conductor. If the material's melting point is significantly below 300 °C, it can lead to insulation burns and ultimately result in malfunction. For instance, the melting point of PE typically ranges from 130 to 135 °C. PP has a melting point that typically ranges from 130 to 171 °C. TPE has a melting point around 60-200 °C. PFAS materials, on the other hand, have high melting points up to 327 °C. The melting point of the material is crucial in ensuring the insulation's integrity and preventing malfunctions.

[74] Supplier Survey 2023; RCOM Ref. 4011, 3909, 3961
[75] Supplier Survey 2023
[76] RCOM Ref. 4011
[77] Supplier Survey 2023, RCOM Ref. 4011

In addition, the operating temperature must be taken into account. The operating temperature for DC cables can go up to 80°C. TPE has a low melting point below 80°C, while other materials have melting points above 80°C.
PFAS is the only type of material that remains structurally stable and does not deform or melt under both two conditions, which results from its exceptional heat resistance and thermal stability. This characteristic is crucial in ensuring the safety of the cable.

- **PE, PP and TPE have relatively low flame-retardant ratings as compared to PFAS**
  High flame resistance is essential for the DC cables used in consumer electronics as it plays a significant role in ensuring user safety and protecting property. Manufacturers need to prioritize incorporating flame-resistant materials in DC cables to meet stringent safety requirements.
  PFAS materials exhibit excellent flame retardant performance and have a UL flammability rating of V-0. PP, PE and TPE materials cannot achieve the same flame retardant rating as PFAS materials.

- **PE and PP have lower mechanical flexibility as compared to PFAS**
  The flexibility and durability for DC cable application is essential to ensuring that the cables can withstand mechanical stress, bending, and dynamic movement without failure. The elongation at break value for FEP typically ranges from 300% to 400%, PP is less than 100%, PE is above 100% and TPE can exhibit a range from 300% to 500% depending on the specific type, grade, and formulation. TPE is a good alternative in terms of flexibility and durability, but it is important to note that flexibility and durability along not guarantee to meet the relevant safety requirements.

- **PVC has poor high temperature stability**
  PVC is often used as wire insulation for moderate temperatures. It can however not be used for temperatures above 70~100 °C. Another disadvantage is the halogen content of PVC.

Substitution:
- The supply chain has reported potential alternative materials to replace PFAS in DC cable applications. However, it will require significant product resign and requalification, and may reduce the safety performance of the cables. The time required to verify the alternative materials is at a minimum:

- 12 months for cable level development and testing: develop specification of raw cable, update manufacturing process, and cable reliability testing and certification.
- 12 months for device level integration testing and certification.
  - If the alternative material does not work, the time required to develop a new material that meets all the safety and performance requirements is unknown. It is estimated to take at least 1-2 years for suppliers to study, screen and identify a potential substitute.
- After successful implementation in a single product, a similar cycle of development and testing is required for the entire product portfolio.

5.2. Coaxial cable and discrete cable insulation and jacket

Name of PFAS substance(s) PFA, FEP, PTFE

CAS Number(s) 26655-00-5, 25067-11-2, 9002-84-0

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify.

The key functionalities provided by PFAS for the relevant use[78]

1. Compliance with safety standard UL1354
2. High temperature stability
3. Melting point of FEP is 285°C , PTFE is 327°C and PFA is 305°C. These are significantly higher than potential alternative materials
4. Good electrical performance which ensures reliable signal transmission over a wide range of frequencies. PFAS has low dielectric constant which minimizes signal loss when it's being transferred through the cable hence maintaining excellent signal integrity. Application may malfunction without excellent signal integrity.
5. Low dielectric constant which enables smaller cable diameter (compared to using alternative materials) while maintaining the required electrical performance
6. High insulation resistance and dielectric strength which improves cable reliability and safety, preventing breakdown of equipment, insulation issue or short circuit accidents
7. High flame retardant ratings
8. The UL flammability ratings of FEP, PFA and PTFE are V-0. This is essential to ensuring the safety of the product. Alternative materials typically have lower flammability ratings and therefore could compromise the safety of the product.
9. High mechanical flexibility

   Fluorinated polymers, like FEP and PTFE possess superior Shore D hardness compared with PE and PP:

Material	Shore D
PTFE	D55
PFA	D60
FEP	D55
PVDF	D80
PEEK	D85
PE	D60-D70
PP	D77-D83

   The material with lower Shore D hardness provides better flexibility and better durability. Some cables, like antenna cables, in electronic device often need to pass through the hinge and then must be abraded and rotated following hinge operation. The high shore D hardness insulator cannot be an adequate buffer for the conductor inside, and therefore the conductor cannot bear the frequent twist and abrasion. The

[78] Supplier Survey 2023, ChemSec 2023; RCOM Ref. 4011, 3909, 3691

low hardness of PTFE, FEP and PFA can provide an adequate buffer to protect the conductor and also bear the frequent twist and abrasion. This feature also ensures a longer life cycle for cables used in electronic devices.

10. High chemical resistance: Fluorinated polymers, no matter whether FEP or PTFE, are inert to acid and base. This is a key character of FEP and PTFE for safety to ensure the well protection on the conductor inside.

For which uses of PFAS is there no alternative?

Outlook: Analysis by ChemSec highlighted a high degree of uncertainty whether alternatives were available. This has been corroborated through extensive supplier engagement. No alternatives have yet been found that meet the properties offered by these two substances in this use.

R&D activity: PE and PP, TPE, PVC and silicone resins have been evaluated as alternatives.

- **Non-PFAS materials cannot meet high frequency electrical performance requirements**
  PFAS materials (PTFE, FEP, PFA) are effective in handling high-frequency signals - they can meet the attenuation requirement and support signal transmission over a wide range of frequencies from a few megahertz (MHz) to several gigahertz (GHz) or higher. On the other hand, TPE, PP, PVC, and PE have a frequency range that only extends from a few kilohertz (KHz) to several hundred megahertz (MHz), rendering them unable to meet the gigahertz-range application requirements. A thicker cable insulation might solve this problem, but this does not fit in all applications.
- **Using non-PFAS materials will result in larger cable diameter which does not meet the required specification of a coaxial cable**
  A coaxial cable must have its characteristic impedance controlled, most commonly at 50Ω, to transmit a signal. The value of characteristic impedance changes depending on the dielectric constant of the insulated core and the outer diameter of the insulated core. If a material with a high dielectric constant is used to insulate the coaxial cable, the cable diameter will be increased. Therefore, it is necessary to use materials with a dielectric constant as low as possible for the insulation of coaxial cables. PFAS materials have a dielectric constant that is lower than that of non-PFAS materials. FEP, PFA and PTFE have a relative dielectric constant of 2.1, and is characterized by being able to form an insulating coating as thin as 0.02mm by extrusion molding. On the other hand, PVC has a dielectric constant of 3.1 to 7.0, and the minimum thickness that can be extruded is 0.15mm. Therefore, if the coaxial cable using PFA has an outer diameter of 1 mm, the coaxial cable using PVC will have an outer diameter of 1.4 mm. Similarly, in the case of TPE, it has a dielectric constant is 3 to 8, and the minimum thickness that can be extruded is 0.2 mm, so the outer diameter of the coaxial cable will be 1.8 mm. The dielectric constant of silicone resin is 2.6~3.7, and the minimum thickness that can be extruded is 0.05mm. Therefore, the outer diameter of the coaxial cable will be 1.06mm.
  In summary, resins other than PFAS have a larger dielectric constant and a larger minimum wall thickness that can be extruded, so the outer diameter of the cables will be larger and cannot meet the product specification.
- **PE, PP and TPE have relatively low melting points compared to PFAS and cannot meet the high temperature stability requirements**
  The melting point for the insulation material is key to coaxial cables and discrete cables. This is particularly crucial due to the soldering/welding process involved in the manufacturing process. When soldering, temperatures around 300°C are transmitted

to the insulation through the conductor. If the material's melting point is significantly below 300 °C, it can lead to insulation burns and ultimately result in malfunction. For instance, the melting point of PE typically ranges from 130 to 135 °C. PP has a melting point that typically ranges from 130 to 171 °C. TPE has a melting point around 60-200 °C. PFAS materials, on the other hand, have high melting points of up to 327 °C. The melting point of the material is crucial in ensuring the insulation's integrity and preventing malfunctions..

During use phase of electronic products, PP and PE cable jackets are not suitable for high temperature applications.

- **PE, PP and TPE have relatively low flame retardant ratings as compared to PFAS** High flame retardancy is essential for coaxial cables and discrete cables used in consumer electronics as it plays a significant role in ensuring user safety and protecting property. Manufacturers need to prioritize incorporating flame retardant materials in cables to meet stringent safety requirements. PFAS materials (PTFE, FEP, PFA) exhibit excellent flame retardant performance and have a UL flammability rating of V-0. PP, PE and TPE materials cannot achieve the same flame retardant rating as PFAS materials.
- **PE and PP have lower mechanical flexibility as compared to PFAS** The flexibility and durability for coaxial cable and discrete cable application is essential to ensuring that the cables can withstand mechanical stress, bending, and dynamic movement without failure. The elongation at break value for FEP typically ranges from 300% to 400%, PP is less than 100%, PE is above 100% and TPE can exhibit a range from 300% to 500% depending on the specific type, grade, and formulation.

  TPE is a good alternative in terms of flexibility and durability, but it is important to note that flexibility and durability along not guarantee to meet the relevant safety and electrical performance requirements.
- **PVC was also disregarded due to its halogen content and poor high-temperature stability[79]**
- **Silicones have lower mechanical strength**

  Silicone wire insulation can withstand temperatures up to 180 °C. However, its tensile strength and mechanical properties are not good enough. ChemSec also confirmed that rubber substitutes have less mechanical strength and less abrasion resistance and that silicone insulation would lead to chemical deposition on the sensors, leading to malfunctions. [Source: ChemSec 2023]
- **Non-PFAS materials are not as resistant to chemicals as PFAS materials**

  When there is a risk of cables being exposed to chemicals, the jacket must be resistant to these chemicals. The material of choice depends on the chemicals it has to be resistant to. To some chemicals only PFAS materials are resistant.

Conclusion

It can be concluded that alternative materials do have some of the required properties and are suitable for use in less-demanding applications. However, for more demanding applications only PFAS materials have all the required properties.

[79] Supplier Survey 2023

Substitution:

- The time required to develop a new material that meets all the safety and performance requirements is unknown because for some properties no material is currently known. It is estimated to take at least 2 years for suppliers to study, screen and identify a potential substitute.
- If a substitute is eventually available, the time for substitution is at a very minimum:
    - 12 months for cable level testing: develop specification of raw cable, update manufacturing process, cable reliability testing and certification
    - 15 months for device level integration testing and certification.

5.3. Connector jacket

Name of PFAS substance(s) PTFE, FEP

CAS Number(s) 9002-84-0, 25067-11-2

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify.

The key functionalities provided by PFAS for the relevant use[80]

1. Good dielectric properties
2. High/low temperature stability
3. Good chemical resistance
4. Mechanical properties of resin

Limited data from supply chain

For which uses of PFAS is there no alternative?

Outlook: ChemSec's research has been unable to find an alternative that delivers all of the critical properties in cables and connectors (ChemSec, 2023) which has been corroborated through extensive engagement with suppliers.

R&D activity: Alternatives examined by the industry for connector applications include PA and LCP, but there is no positive result yet.[81]

In general, products using alternatives cannot meet at least one of the safety or performance requirements (mechanical properties, dielectric strength, flame retardancy, temperature and chemical stability).[82]

[80] Supplier Survey 2023
[81] Supplier Survey 2023
[82] RCOM Ref 4011

Substitution:

- The time required to develop a new material that meets all the safety and performance requirements is unknown. It is estimated to take at least 2 years for suppliers to study, screen and identify a potential substitute.
- If and when a substitute is available, it is estimated to take at least 12 months to produce and qualify the new part.

Proposed derogations – Cables/Connectors

Paragraph 2(c) shall apply from (**13.5 years** after entry into force) to **fluoropolymers in cable insulation and jacket and connectors**.

5.4. Socio-economic impacts

The consequential economic (in euros) and social (e.g. jobs) impacts arising from any restriction of PFAS in respect to its use in cables and connectors are difficult to quantify. However, significant financial costs can be expected to arise because of the inability to substitute and because of the strategic importance the EU has placed in developing an advanced digital and data economy as part of its European Data Strategy & communication "Shaping Europe's digital future"".

1. Annual value of EU sales: In 2022, the computer hardware market in Europe generated a total revenue of over 60 billion euros, selling around 630 million units. Storage units made up the majority of volume at approximately 462 million units, followed by laptops and keyboards, both with approximately 42 and 40 million units sold, respectively[83]
2. Indirect costs - European employment in the ICT sector: In 2022, more than 9 million persons worked as ICT specialists across the European Union (EU). The highest number (2.1 million) worked in Germany, which provided work to more than one-fifth (22.6 %) of the EU's ICT workforce. France (1.2 million) had the second largest ICT workforce (13.0 % of the EU total), followed by Italy and Spain (both 0.9 million; 9.6 % and 9.4 % respectively).[84]
3. Indirect European employment - data professionals: Professionals working in the new and growing data economy rely on the efficient transfer of data. When publishing the EU's data strategy for the EU, the number of data professionals was expected to grow from 5.7m in 2018 to 10.9m in 2025, touching nearly every sector across the economy.
4. Indirect financial consequences of less efficient data transmission: The European Commission estimates that the EU's data economy will be worth €829 billion in 2025, from 2% to 6% of regional GDP[85]
5. Wider economic impacts - expected growth: Christensen et al (2018) estimated, using the RHOMOLO model, that implementing the third pillar of the Investment Plan for

[83] Statista, 2023, https://www.statista.com/forecasts/1256748/volume-segments-computer-hardware-europe
[84] Eurostat, 2023, ICT Specialists in Employment, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment#Number_of_ICT_specialists
[85] EU factsheet, https://ec.europa.eu/commission/presscorner/detail/en/fs_20_283

Europe, including efficiency gains from the Digital Single Market, would contribute to a 1.5% increase in GDP per year until 2030 and create between 1 and 1.4 million jobs.[86]

6. R&D, retooling, retesting, recertifying supply chain costs: not able to be estimated.
7. Fluoropolymer related impact[87]

   Employment:

   - Indirect and induced employment resulting from the production of fluoropolymers: The average GVA per employee in relevant industries is €100,000.
   - Overall, in the EU around 4,500 employees are directly employed in manufacture of fluoropolymers, and in the wider sector an estimated 4,400 people. This suggests some 8,900 people in total are sustained directly and through indirect and induced effects by the production of fluoropolymers. This does not include employment in sectors using fluoropolymers, which is many multiples higher. (P23)
   - Volumes of fluoropolymers placed on the market in the EEA in 2020: Around 40,000 tonnes of fluoropolymers estimated to be sold in EEA (P10)
   - Growth projections: The EU Chips Act is anticipated to allow the EU to reach its ambition of doubling its current market share of semiconductor technology to 20% in 2030. This indicates that fluoropolymers will likely follow a similar trend over this period. (P11)
   - Sales value of products sold in the EEA in 2020: €750million (P14)
   - Two estimates of Downstream applications market of fluoropolymers in EU: sales to electronic sector in 2020:
     - 3,500 tonnes of fluoropolymers, value: €70 million (source: 2017 FPG SEA study)
     - 4,000 tonnes and €80 million (source: studies supporting PFAS restriction proposal)

   Note: this means the EU electronics sector is around 10% of fluoropolymer volumes in the EU. Sales value estimates are consistent at approx. 10%.

[86] M. Christensen, A. Conte, F. Di Pietro, P. Lecca, G. Mandras, & S. Salotti (2018), The third pillar of the Investment Plan for Europe: An impact assessment using the RHOMOLO model (No. 02/2018). JRC Working Papers on Territorial Modelling and Analysis

[87] FPG 2022 report https://fluoropolymers.plasticseurope.org/application/files/1216/5485/3500/Fluoropolymers_Market_Data_Update_-_Final_report_-_May_2022.pdf

6. Capacitors

Name of PFAS substance(s) PTFE, PTFE co-polymer, Poly(difluoromethylene),. alpha.-(cyclohexylmethyl)-.omega.-hydro-, etc.

CAS Number(s) 65530-85-0

General summary of the application category

PFAS is used in several materials such as electrodes (anode), masking, seals, coatings, insulators, and paste materials. The properties they provide include:

- highly reliable seal against electrolyte diffusion along the tantalum anode wire.
- resist distortion during the oxidation and impregnation process.
- binder for electrodes – similar application as PFAS in batteries

Non-PFAS Alternatives Identified Through the Supply Chain or Research

The electronics industry has a very deep and complicated supply chain which operates on a global basis. Ascertaining data on feasible non-PFAS alternatives for capacitors has yielded no drop-in replacements to date. Nonetheless, the investigation will continue indefinitely.

Moving beyond the supply chain and focusing upon research into non-PFAS alternatives has required an extensive literature review to determine what if any non-PFAS alternatives are being considered for capacitors. The on-line library search engine utilised for this review was Summon™.

Error! Reference source not found. illustrates the keywords/phrases utilised in an effort to comprehend what research into non-PFAS alternatives for capacitors has taken place or indeed is still on-going.

Keyword or Phrase	# of Results	Results of Relevance to PFAS in Cables/Connectors/Capacitors
PFAS	68,857	Reviewed the first 1,000 results. None of them were relevant.
PFAS in electronics	1,791	None
Non PFAS alternatives in electronics	19	None
PFAS alternatives in electronics	78	None
Fluoropolymer alternatives in electronics	84	Most of the results focused upon fuel cells, membrane materials for alternative energy and sustainability applications. None were relevant for cables, connectors and capacitors.
PFAS in capacitors	62	There were some relevant results, but the papers emphasised the benefits of fluoropolymers in capacitors.
Fluoropolymer alternatives in capacitors	5	None

Table 5 PFAS literature review for non-PFAS alternatives in cables, connectors and capacitors

Based upon the findings in **Error! Reference source not found.**, it is apparent that if there is on-going research into non-PFAS alternatives for capacitors, none of it is finding its way into the public domain. This scenario is more than likely a result of the lack of research into these electronic components/products.

The combined lack of data on non-PFAS alternatives from the supply chain in conjunction with the lack of research into these electronic components/products, surmises that there are no drop in alternatives currently available and the likelihood of such alternatives being available at the entry into force timeframe is questionable.

Proposed derogation

Consequently, it is requested that a derogation covering the uses of various capacitor types is granted from the proposed REACH Restriction on PFAS for **13.5 years** after entry into force.

7. Grease & Lubricants

7.1. Grease/lubricants on mechanical parts in EEE

Name of PFAS substance(s) PTFE; Perfluoropolyether (PFPE) oil; Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd.

CAS Number(s) 9002-84-0; 60164-51-4; 69991-61-3

General summary on the application category

PFAS-containing greases are used on mechanical parts (e.g. hinge of laptops) in electronic products. These greases are used because they offer a low friction coefficient, have a wide service temperature range, are chemically inert, oxidation resistant, and have excellent material compatibility.

The use of PFAS greases are essential to ensuring long service life and durability of the products. Product durability is a key focus of policy efforts as part of the Circular Electronics Initiative and has been a key feature in the review of Ecodesign Regulation 617/2013 (Lot 3) - Computers and Computer Services.

As an example, laptop hinge lifecycle test is one of the many tests that are conducted to ensure the durability of the devices. As of yet, no alternatives can meet the industry standard durability requirements. For alternatives tested so far to replace PFAS, the projected part service life is (at a maximum) approximately half of the service life achievable by using PFAS.

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify.

The key functionalities provided by PFAS for the relevant use[88]

1. Lowest known coefficient of friction (≤ 0.1)
2. Stable coefficient of friction and wear resistance over extended period of time
3. Chemically inert, oxidation resistant and excellent material compatibility
4. High temperature stability and wide service temperature range (-35℃-250℃)

For which uses of PFAS is there no alternative?[89]

Outlook: Despite extensive exploration, suitable alternatives have yet to be identified.

R&D activity: Among the substitutes trialed are PE, graphite, molybdenum(IV) disulfide, PVD surface treatment and even no grease entirely.

1. Not using grease at all on computer hinge frames and supports, resulted in the hinge breaking after a limited number of lifecycle tests which corresponds to less than 5% of the target service life time of the part.

[88] Supplier Survey (2023)
[89] Supplier Survey (2023)

2. Alternative surface treatment, such as Physical Vapor Deposition (PVD), was trialed. The intention of PVD is to achieve lower roughness of the surface, which is helpful to lower the friction between different surfaces. This has failed due to poor bonding between the surface and the PVD layer, as the PVD layer peeled off after a limited number of lifecycle tests which corresponds to less than 5% of the target service lifetime of the part. The peeled-off PVD layer also increases the friction of the hinge, therefore further reducing the hinge life.
3. Use of high precision turning process to achieve low roughness of the surface. This has failed to meet lifecycle and torque degradation requirements.
4. Use silicone or polyol ester to replace PFAS. However, both failed due to inadequate lubricant ability and inadequate thermal stability. These features of PFAS make it irreplaceable so far, especially with regards to extending the lifecycle of electronic devices.[90]

	Thermal Stability	Oxidation Stability	Hydrolytic Stability	Fire Resistance	Lubricating Ability
PFPE	E	E	E	E	E
Polyol Ester	G	G	G	G	G
Silicone	G	G	G	G	P

E: excellent; G: good; P: poor.

5. The use of other solid lubricant such as graphite and Molybdenum(IV) disulfide cannot pass the lifecycle test. Estimated service life for parts using these lubricants is approximately half of the service life achievable by using PFAS grease/lubricants.

Substitution: Time for substitution

- The time required to develop a new material that meets all the performance requirements is unknown. It is estimated to take at least 1-2 years for suppliers to study, screen and identify a potential substitute.
- Once a potential substitute is identified, it will take 1.5-1.8 years for material qualification (grease stability after aging, tribology test) and Hinge qualification (assembly + reliability test, part level assembly + reliability test, device level assembly + reliability test).
    - If the alternative material does not work, the time required to develop a new material that meets all reliability and performance requirements is unknown. It is estimated to take at least 1-2 years for each study and screening cycle to identify potential candidates.

Proposed derogation

Paragraph 2(c) shall apply from **(13.5 years** after entry into force) to **grease and lubricants** used in electrical and electronic equipment.

[90] Driving Auto Performance Through Lubricant Selection (https://pages.chemours.com/rs/509-VCL-038/images/Whitepaper_Auto_101_2017edits.pdf)

7.2. Lubricant in connectors

General summary on the application category

Plug-in connections are used wherever components or assemblies need to be connected temporarily. Electrical contacts have basically two main tasks: the possibility to mechanically separate an electrical connection and the transmission of electrical energy without losses in closed position.

As they are used in a wide range of different environments, like heat or damp heat, the contact surface of the electrical contact has to meet various requirements. Further, fretting corrosion continually exposes fresh layers of the metal surface to oxidation.

PFAS containing lubricants are used in gold-plated connectors to protect the part against oxidation and fretting corrosion, while also minimizing degradation through contact wear, thus helping to extend the connector life (Supplier Survey, 2023).

Product durability is a key focus of policy efforts as part of the Circular Electronics Initiative and has been a key feature in the review of Ecodesign Regulation 617/2013 (Lot 3) - Computers and Computer Services.

A thin film of lubricant can also reduce mating force by as much as 80 percent, an important factor in connector assembly. For electronic connectors with dozens or even hundreds of pins, a low insertion force helps to ensure solid connections.

No alternatives have been successful to replace PFAS to date.[91]

The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use

Insufficient information to quantify - may reference Cefic socio-economic study once it becomes available.

The key functionalities provided by PFAS for the relevant use

1. Low coefficient of friction (≤ 0.1) which protects the connector from mating and unmating forces and improves durability
2. High corrosion resistance
3. Stable coefficient of friction and wear resistance over extended period of time
4. High temperature stability and wide service temperature range (-35℃-250℃)

For which uses of PFAS is there no alternative?

Outlook: No alternatives have been identified to date. ChemSec suggested alternatives have proved to be unsuccessful substitutes.

R&D activity: Supply chain reported that all the potential alternatives evaluated so far contain PFAS. Other non-PFAS wax or grease are not suitable for industrial use. Suppliers are actively looking for alternative coating liquid that is not sticky in the manufacturing process, which has been the case when testing silicone alternatives.[92]

[91] Supplier Survey (2023)
[92] Supplier Survey (2023)

Alternative dry coatings have been tested and failed for either corrosion or cosmetics. Alternative lubricants have been tested and do not meet performance requirements.[93] After some usage, the coating is also peeled off easily and then peeled-off particles further increase the surface friction. The higher surface friction reduces the lifecycle of parts.

Substitution:

- The time required to develop a new material that meets all the performance requirements is unknown. It is estimated to take at least 1-2 years for suppliers to study, screen and identify a potential substitute.
- Once a potential alternative is identified, it will take 1.8-2 years for testing lifecycle, assembly line optimization, and evaluation of mass production.
    - If the alternative material does not work, the time required to develop a new material that meets all reliability and performance requirements is unknown. It is estimated to take at least 1-2 years for each study and screening cycle to identify potential candidates.

Proposed derogation

Paragraph 2(c) shall apply from **(13.5 years** after entry into force) to **grease and lubricants** used in electrical connectors.

[93]ChemSec (2023), Check Your Tech: A guide to PFAS in Electronics, https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fchemsec.org%2Fapp%2Fuploads%2F2023%2F04%2FExcel_ChemSec-Electronics-Guide.xlsx&wdOrigin=BROWSELINK

8. Cooling in data centres

Introduction

The growth rate of data volume globally is nothing but astonishing. Information produced by the EU Commission as part of its EU Data Strategy illustrates a phenomenal 530% increase predicted from 2018 to 2025. Indeed, it is estimated that during the same timeframe, the value of the data economy to the EU will grow from €301 in 2018 to €828 billion by 2025 (Figure 5.0).

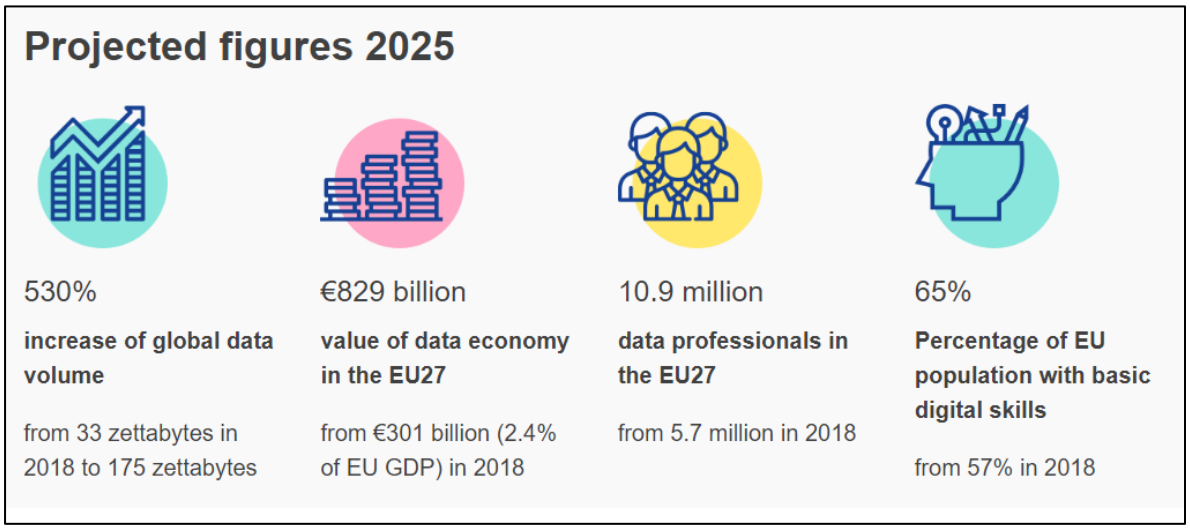

Figure 5 EU Data Strategy projected figures for 2025

In an effort to sustain or meet such data demands, there needs to be an equivalent increase in computational power. It's not just a case of doing more of the same as what's been done in the past to augment the necessary computational power. The growth rate of Artificial Intelligence (AI) and high-performance computers has driven the need for more powerful processors and hardware accelerators. This has resulted in generating significant increases in silicon or processor thermal design power (TDP) beyond 1kW/each processor and semiconductor package thermal density.

These semiconductor devices are housed in servers which in turn are accommodated in data centres. Simultaneously, there is regulatory focus on reduced energy consumption, increased energy efficiency at data centre level, reuse of waste heat from data centres as well as meeting sustainability goals. Together these trends are creating significant strain on today's data centres which require alternatives to today's state-of-the-art cooling technologies to handle the coming data demands.

Issues with Current Cooling Technologies

Cooling of data centres is frequently the largest energy loss in the facility and as such represents a significant opportunity to improve efficiency. The primary cooling methods employed in data centres are air and water based.

The objective of airflow management is to circulate only the necessary amount of air through the data centre at any time that is required to remove the heat actually created by the IT equipment. This means no air returns to the cooling system without absorbing heat and no air

circulates more than one time through the IT equipment.[94] When considering water-based cooling methods, the water utilised needs to be sufficiently chilled which can have a significant impact on the data centre's energy efficiency. Due to the changing climate, water is becoming a precious commodity in several geographies across the globe including the EU and several regulations are being imposed on data centre operators to limit the use of water for data centre cooling applications such as towers or evaporative air cooling. Also, to cool high wattage processors, water needs to be chilled using chillers therefore reducing the overall efficiency of cooling solutions.

These air- and water-cooled methodologies are becoming increasingly inefficient with the cooling load required for the greater demands of server products. Consequently, alternative cooling methodologies have been investigated to cater for today's requirements but more importantly future needs as well.

Alternative Cooling Technologies

Unfortunately, there are no commercially available alternatives that address the future needs for high TDP, high heat flux silicon, and global energy efficiency demands that have no PFAS chemistry. Traditional forced air cooling has already been optimised within the practical limits of data centre airflow delivery. Traditional propylene glycol-water based fluids support high TDP but fall short on supporting high package thermal density as compared to pumped refrigerant 2-phase cooling. Also, due to the lower effective heat transfer of legacy liquid cooling methods, more power is required for primary loop water chillers and secondary loop fluid pumps (Figure 2.0) when compared with the pumped refrigerant 2-phase cooling method (Figure 3). It's important to note that water or air chillers used for current data centre cooling is already or will be shortly using one of these hydrofluoroolefins (HFO) refrigerants.

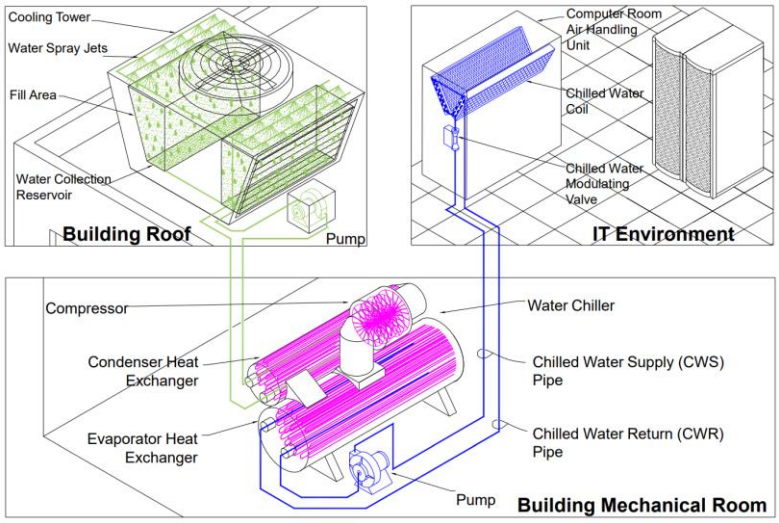

Figure 6 Traditional air-cooled data centre using water-cooled chiller system[95]

Put another way, refrigerant-based server level cooling allows deployment of AI silicon into markets where warm facility water usage is required to meet its energy efficiency and sustainability targets.

[94] Joint Research Centre (2023) Best Practice Guidelines for the EU Code of Conduct on Data Centre Energy Efficiency. European Commission.
[95] Image courtesy of Schneider Electric

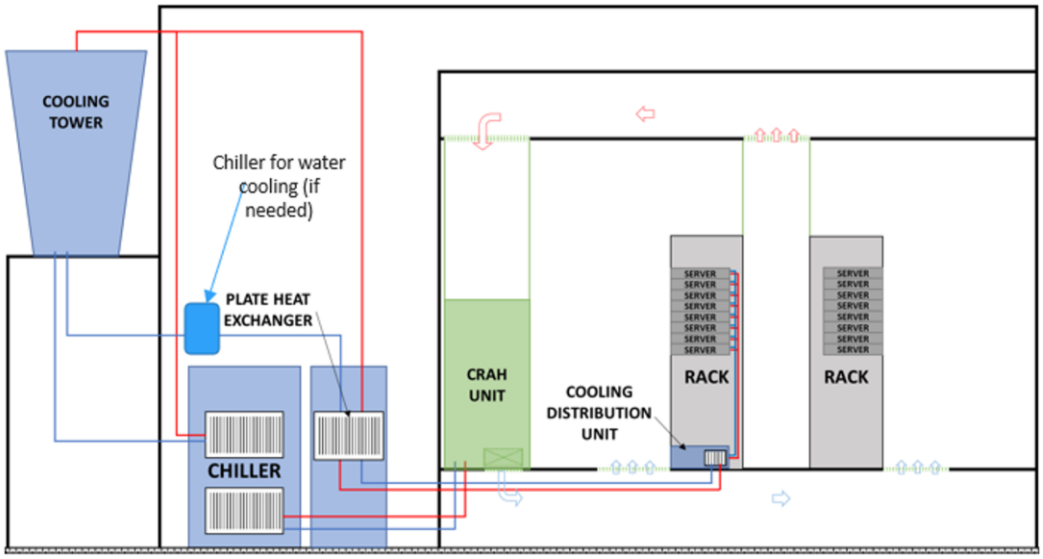

Figure 7 Hybrid air cooled data centre using propylene glycol fluid in server racks with water cooled chiller system or pumped refrigerant fluid in server racks eliminating high power water-based chiller systems

The use of F-gases particularly HFOs have shown to be extremely efficient in performing the required cooling of server products in data centres through this application known as two phase liquid-vapour cooling. This involves the circulation of low-to-medium pressure refrigerants (HFOs) through cold plates attached directly to high-powered AI silicon.

In this approach, the refrigerant is circulated through cold plates as a saturated liquid, absorbing heat from processors before it vaporizes. Due to higher latent heat of vaporization (compared to just sensible heat for single phase water-based cooling), the process requires relatively small pumping power and is vastly more capable and efficient than traditional air and water-based cooling methods. Please note this is a different technology to what is known as immersion cooling. The HFOs of interest that fulfil this cooling distribution function are captured in Table 6.0.

Refrigerant	Pressure	Chemistry	GWP	ODP	Toxicity	Flammability
R513A	medium	HFC/HFO	573	0	low	zero
R515B	medium	HFO	299	0	low	zero
R1234ze	medium	HFO	6	0	low	mild
R1234yf	medium	HFO	<1	0	low	mild
R1233zd	low	HFO	1	0	low	zero

Table 6 Suitable HFOs for Date Centre Cooling

The characteristics of the HFOs outlined in Table 6.0 illustrate excellent global warming potential which significantly supports the EU's climate ambition's goals as the more typically utilised F-gases in data centres such as R134a and R410a have global warming potentials of 1,430 and 2,088 respectively. One major advantage of these medium pressure refrigerants is with their low boiling point (well below traditional atmospheric temperature) if emitted or leaked,, it would immediately vaporize and not contaminate soil or ground water. Also, the half-life of these refrigerants is very short compared to traditional PFAS coatings and other compounds.

The cooling system itself is known as a cooling distribution unit (CDU) and is a closed system. This hardware utilises fluoropolymers such as gaskets and seals given their unique characteristics in addition to prolonging the service life of the CDU. There are no intentional releases of the HFOs with this technology. Currently there is less than one tonne of HFOs utilised globally for this application. These refrigerants are handled only by trained technicians as per HVAC industry protocols who have passed extensive certifications such as those outlined in the EU F-gases regulation, US EPA 608 etc. Hence, the safe use and handling of these refrigerants is already being monitored and is not handled by any non-certified technicians.

Suitability of Dossier Submitter Proposed Non-PFAS Alternatives

The Dossier Submitter in its Annex XV report proposed several non-PFAS alternatives for electronics cooling in data centres. Two of these proposed alternatives - Hydrocarbon Systems and Ammonia - had been questioned by the Dossier Submitters themselves on grounds of flammability and toxicity issues which would reside inside the data centre hall. The other non-PFAS alternatives such as basic ventilation, small-scale air-conditioning systems and water are simply not feasible given the pending demands of cooling technologies with the anticipated growth in data volume.

Critique of Dossier Submitter Conclusions Concerning HFO Emissions

The HFOs outlined in Table 6.0 which are needed to run this cooling distribution technology are known to degrade in the atmosphere to trifluoroacetic acid (TFA). Although, the cooling technology is not designed to release HFOs, it is important to stress the degradation profile of these F-gases to illustrate the low risk they pose to the environment and consequently should be seen as a viable and pragmatic solution to the current and pending cooling demands within data centres.

The Dossier Submitter noted in the PFAS Annex XV report in the section dealing with PFAAs (arrowheads and precursors), “as most of these substances are expected to ultimately degrade in the environment to TFA (details in Annex B.4.1.), they will contribute to the overall exposure to and risks of PFAAs”. Such a statement or indeed conclusion by the Dossier Submitter is not accurate when examined against the number of peer reviewed studies conducted and even ECHA itself on TFA. According to the trifluoroacetic acid (TFA)[96] REACH registration dossier and Chemical Safety Report (CSR), this substance does not fulfil the criteria for a PBT or vPvB substance under Annex XIII REACH. Neither does it raise equivalent levels of concern under Article 57(f) REACH.9In this respect, ECHA already reviewed/evaluated the TFA dossier without concluding that further regulatory actions were needed. The United Nations Environment Programme (UNEP) in its Environmental Effects Assessment Panel in 2020 noted that “Historical and current measurements of TFA in soil and surface-water indicate de minimis risks when compared to no-effect-concentrations (NOECs) in laboratory and field-based testing”. UNEP also called out what they identified as erroneous claims that TFA was toxic to plants, and to set the record straight stated that “There is no scientific basis for this conclusion and risks from current and future releases of TFA from the use of fluorinated precursors regulated under the Montreal Protocol to aquatic and terrestrial plants are de minimis”.

In their 2022 report, UNEP highlighted that “There has been considerable discussion as to the inclusion of TFA in the class PFAS for regulatory purposes…We are of the opinion that the

[96] Trifluoroacetic acid, EC no: 200-929-3, CAS no: 76-05-1, Molecular formula: C2HF3O2

properties of TFA indicate that it should not be included in this class for the purposes of generic regulatory risk assessment".

It would appear that the Dossier Submitter and the United Nations Environment Programme have diametric opinions about TFA and consequently HFOs in terms of their risk and suitability for inclusion into a PFAS grouping effort for regulatory purposes.

EU Initiatives

The proposed cooling technology will fully support many of the EU Commission's priority policies. These include Energy and Climate policy, the vast number of initiatives captured under the Green Deal, EU Chips Act and indeed the Digital Decade.

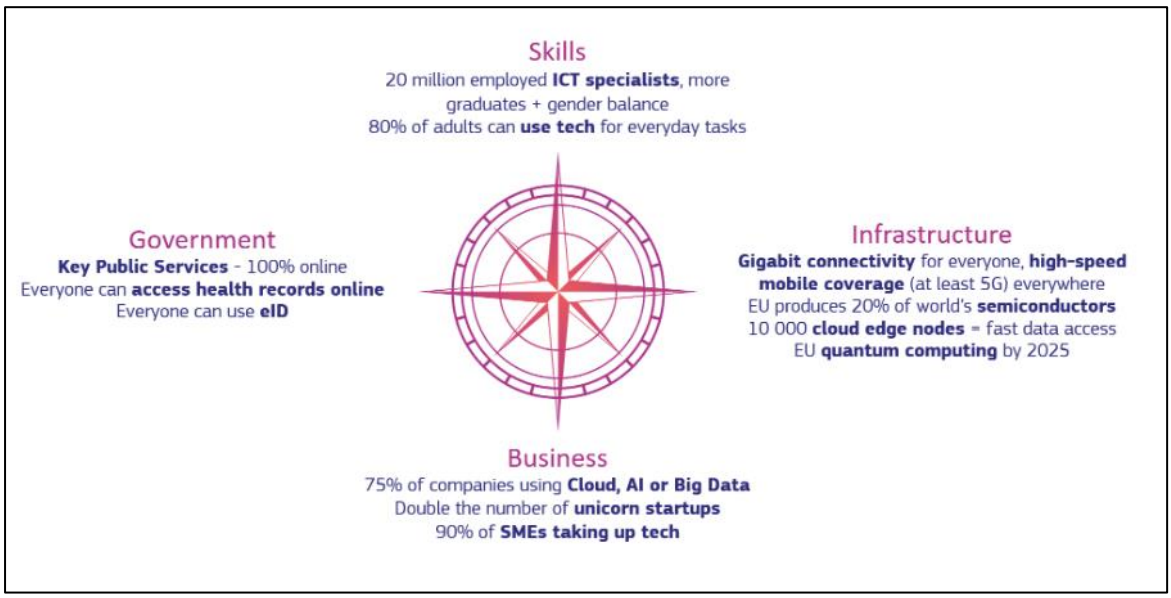

Figure 8 Europe's Digital Decade Targets for 2030

Upon examining the primary strands of the Digital Decade, Figure 8.0 depicts the associated policy programme with targets and objectives for 2030. All of these - Skills, Infrastructure, Business and Government necessitate the use of data centres. It is imperative that these data centres utilise a superior and sustainable cooling technology such as that provided through the cooling distribution systems outlined.

Proposed derogation

Consequently, it is critically important that this technology, including its refrigerant chemistries (HFOs) and hardware (fluoropolymers), are appropriately granted a time-unlimited derogation.

References

ECHA (2023) PFAS Reach Annex XV Restriction Report. European Chemicals Agency.

EU Commission 2023, Digital Decade Strategy, viewed 3rd July 2023, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en

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UNEP (2020) Environmental Effects of Stratospheric Ozone Depletion, UV Radiation, and Interactions with Climate Change. UN Environmental Effects Assessment Panel.

UNEP (2022) Environmental Effects of Stratospheric Ozone Depletion, UV Radiation, and Interactions with Climate Change. UN Environmental Effects Assessment Panel.

9. Mechanical Applications

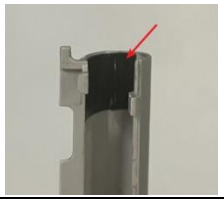
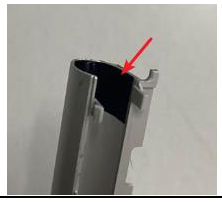
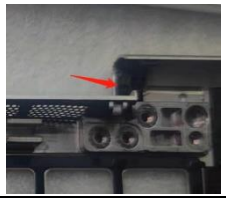
General summary of application category

PTFE is used as an additive in plastic parts to meet tribiology requirements (e.g., friction, wear, lubrication). It is widely used in printers for gears, rollers and other plastic parts that require low friction, wear, and noise.

There is no drop-in replacement for PTFE, but there are potential alternatives materials, such as silicone, wax, polyethylene, aramid, and graphite. **It is unlikely that one material will be able to substitute all of applications of PTFE.**

Another important use of PTFE is Teflon tape. There are a lot of components and parts in one electronic device. Especially in mobile devices, the parts or components may abrade each other during operation. For example, local abrasion causes the conductors to break. Copper is most used as conductor in electronic device because of its good extensibility, good conductivity and abundance in the world. However, even if there is jacket outside to protect the copper wire, the stress or heat of abrasion still can break the copper wire. Teflon tape is often used to increase the durability and robustness in specific locations.

Another example are the coaxial cables in charge of transmitting the signal of antenna module to the circuit board. The coaxial cables pass through the hinge, and the part in the hinge is often abraded when laptops are opened and closed. The stress of the hinge operation may cause the coaxial conductor to break. The best solution to improve cable durability under hinge operation is to apply Teflon tape. The coefficient of friction (0.05-0.20) is low and therefore the coaxial cable can be protected.

Purpose	Location	Photos
Protect cable close to hinge cap to reduce the friction between cable and hinge cap.	hinge cap inside	 
Protect cable close to the base close to the C cover horn protrusion. Reduce the friction between C cover inside and cable.	C COVER inside horn protrusion	 

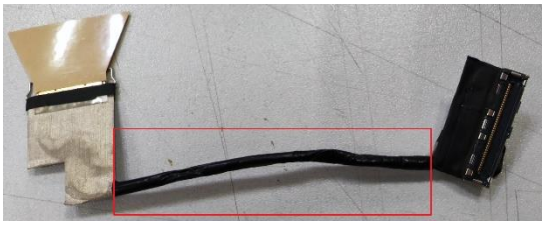
Reduce the abrasion between cable outside and enclosure inside during hinge operation.	1. antenna cable in/out location 2. Hub Cable in/out location 3. EDP Cable in/out location	  

Table 7 Teflon tape application examples

The annual tonnage and emissions and type of PFAS associated with the relevant use

Insufficient information to quantify.

For which uses of PFAS is there no alternative

For the wear-resistance improvement application, HDPE is often the alternative candidate to replace Teflon, because of the similar chemical structure. However, Teflon still has a smaller coefficient of friction (COF) for better durability. Based on COF, PET and PI are also often mentioned to replace Teflon and both these two materials posess good heat resistance. However, the brittleness of PET and PI make the tape less durable than Teflon.

	COF (coefficient of friction)
Teflon	0.05-0.2
PE (HDPE)	0.29
PET	0.19
PI (polyimide)	0.22

It must be noted that PTFE has a much higher heat deflection temperature and corrosion resistance whereas HDPE has an excellent strength-to-weight ratio. Currently there is no alternative for durability-enhancement application in electronic devices. For desktop platforms, like DTO tower, AiO or monitors, the slighter space limitation can use HDPE tapes, PI tapes or PET tapes to enhance the durability by thicker usage. For mobile devices, like laptops or tablets, the components are all compressed in a small space. To get good durability in limited space and achieve the desired lifecycle, Teflon is the only one option so far.

Physical Property	HDPE	PTFE
Melting Point (°C)	120-140	327
Density (g/cm3)	0.96	2.15
Ultimate Tensile Strength (MPa)	31.7	10.3 - 20.6
Water Absorption (ASTM D570) (% by weight)	0.1	< 0.01
Heat Deflection Temperature (°C) @ 0.45 MPa	90	120
Tensile Elongation (%)	600	100 - 200
Dielectric Strength (kV/mm)	17 - 24	20 - 48

Proposed derogation

Paragraph 2(c) Shall apply from (**6.5 years** after entry into force) to **PTFE and Teflon tape used in mechanical applications for electronic equipment**. By (18 months before the derogations are due to expire) the Commission will review derogations in light of new scientific available information and information on alternative materials or processes and if appropriate, modify this derogation accordingly.

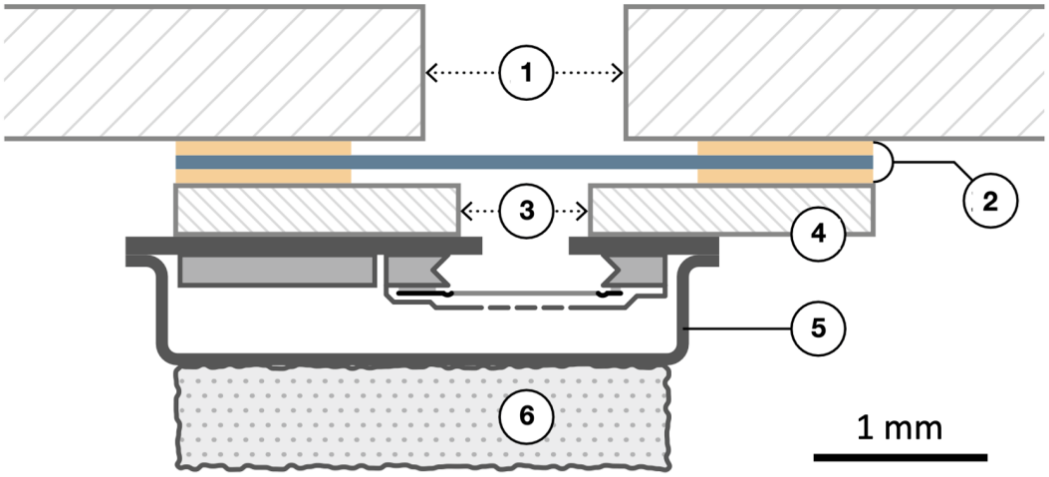
10. Ingress Protection Vents for Communication Devices

General summary on the application category

Devices used for communications, which includes smartphones and wearable electronic devices like smart watches and wireless headphones, have become a part of everyday life for citizens in Europe and critical for use in emergencies. In 2022, approximately 200 million smartphones and 80 million wearable devices were sold in the EU[97]. These devices must have openings to the environment to allow for pressure equalization, the transmission of acoustic signals to and from microphones and speakers, and to enable sensors to collect environmental data like air and water pressure. Users expect that their device will not be damaged or destroyed if it falls into water, is exposed to rain, or is cleaned.

Due to the sensitive nature of the electronics (microphones, speakers, sensors, circuits) in these devices, they can be easily damaged by particulates, water, oils, cleaners and other contamination.

To overcome this issue, device manufacturers provide ingress protection by using a PFAS-based microporous vent. The protection helps eliminate component failures, extends the life of the device, and reduces the environmental waste from prematurely replaced devices. These vents contain an extremely low mass of PFAS, are often only 4 mm in diameter and weigh approximately 40 µg. Without effective protection against external contaminants such as liquids and dusts, devices fail and must be replaced. Figure 9 illustrates how a vent for air and/or sound transmission is assembled into a typical smartphone.



1: Front cavity
2: Vent for air and/or sound transmission
3: Back cavity
4: Printed circuit board
5: Microphone
6: Compression foam

Figure 9 Ingress protection vent for air and/or sound transmission in a typical smartphone

A derogation for the use of PFAS in Ingress Protection Vents for Communication Devices is needed because:

[97] International Data Corporation (IDC), https://www.idc.com/prodserv/insights/manufacturing/latest-research

- **Protecting communications devices from failure due to liquid or dust ingress is a critical function** for hundreds of millions of EU citizens in personal, professional, and sometimes emergency settings. Increasing the longevity of such devices is also an important factor in reducing electronic waste and the consumption of critical raw materials.
- Currently, **no alternative is available** that would prevent device failure and that would not require PFAS chemistry.
- An **exceptionally low volume of PFAS is required** for this end use in the EU (< 35 kg annually).
- Decades of research has not provided a suitable alternative. If suitable alternative materials are identified in the future as a result of ongoing research, which is currently ongoing, it would take several additional years to develop, test and produce devices that can incorporate the alternative materials.
- Without a derogation, there would be a significant increase in the failure rate of these devices which both the general population and professionals (emergency services, transport operators, etc.) rely on for their daily and urgent communications. This would result in an increase in waste and resource consumption. Furthermore, consumers could face a cost increase of more than €600 per device to replace damaged devices, which at an EU level amounts to a cost of more than €20 billion per year. These costs are not justified given the exceptionally low volume of PFAS required for this end use.

In the following sections we provide detailed evidence for this derogation based:

- The **performance requirements** for ingress protection in devices used for communications
- The **lack of availability of alternatives** that would provide the required level of performance
- The **time required** for research and development to investigate and evaluate potential alternative materials, and if a feasible alternative is identified, the time required to identify develop, test and commercialize a new vent in a device
- The **extremely low volume of PFAS** needed for this application in comparison to the **large socio-economic cost** of restricting the use.

Performance Requirements for Ingress Protection Vents

Ingress protection vents for communication devices have a wide range of unique and technically demanding requirements. The primary challenge is providing ingress protection whilst enabling adequate airflow.

At the device level, a common standard used for communications devices is the Ingress Protection rating (or IP rating), which is an international standard (IEC 60529) used to rate the degree of protection or sealing effectiveness in electrical enclosures against intrusion of objects, water, dust or accidental contact. It corresponds to the European standard EN 60529. A summary of the rating system is shown in table 4 below.

Protection Against Foreign Solid Object (X)		**Protection Against Liquid (Y)**	
0	No protection	0	No protection

1	Protection against solid objects > 50 mm, such as a hand	1	Protection against vertically dripping water, some ingress permitted
2	Protection against solid objects > 12.5 mm, such as a finger	2	Protection against dripping water with enclosure tilted up to a 15° angle
3	Protection against solid objects > 2.5 mm, such as tools	3	Protection against spraying water
4	Protection against solid objects > 1.0 mm, such as wire or small screws	4	Protection against splashing water
5	Dust resistant, limited protection from the ingress of dust, ingress of dust not sufficient to cause harm	5	Protection against jets of water directed at the enclosure
6	Dust-tight, total protection from the ingress of dust	6	Protection against powerful jets of water directed at the enclosure
		7	Protection against submission or exposure to water up to 1 m for a period of 30 minutes
		8	Continuous immersion in more than 1 meter of water for 30 minutes in test conditions subject to agreement between manufacturer and user.
		9k	Protection against high pressure and temperature water jet

Table 8 Ingress Protection (IP) standards : Ingress Protection Rating Format: IP X Y

IP 68 means a total protection from the ingress of dust and continuous immersion in more than 1 meter of water for 30 minutes in test conditions agreed on between a manufacturer and user, meaning that a device with an IP68 rating may be designed to withstand 3 meters immersion or 6 meters immersion. Meeting this rating is critical for everyday and emergency performance.

In addition to IP rating, there are more challenging requirements placed on communications devices that protect from challenges that arise in common use cases. For example, devices must often retain their immersion protection after coming in contact with soapy water, as might happen when a smart phone is cleaned or dropped in a sink, or when a smartwatch is worn during hand washing. This requirement puts more stringent contamination resistance requirements on vents to prevent premature device failure. Soapy water is just one of many potential low surface tension fluids that may challenge vents in this application, all of which are more likely to cause ingress and potential device failure than a pure water challenge.

Microporous Structure - Good Sound Transmission and Ability to Equalize Pressure

The immersion protection capability of a membrane against ingress of liquids or solid particles is determined by multiple factors of which porosity has a large impact. Large pores allow more ingress than small ones. At its extreme, the ultimate material for immersion protection is a full

density, non-porous material (e.g. having no opening, for example a sheet of metal) which allows no liquid ingress. However, this approach does not provide the needed breathability or acoustic properties to function as a vent on a communications device.

The membranes which are used in these vents for air and/or sound transmission need to be a thin and low-mass membrane with mechanical properties and porous microstructure that enable optimal transmission of air and/or sound. In some cases, the membrane vibrates easily and quickly in response to sound waves, converting their airborne energy to mechanical vibrations. These vibrations are reproduced on the other side of the membrane to create high-quality acoustics. In other cases, the vent microstructure is permeable enough to allow direct transmission of the sound waves through the membrane's porosity.

The optimized permeation properties enable the vent structure to rapidly equalize pressure changes due to temperature increases or decreases or air pressure differences as they may occur, e. g., during air transports. The vent structure also protects sensitive electronics against condensation from water vapour entering the device, and minimize stress on device seals originating from high air pressures.

Hydrophobicity and Oleophobicity - Barrier to water and oily liquids

For ingress protection, the material needs to be hydrophobic enabling the membrane to repel water and, at the same time, oleophobic enabling it to repel oily fluids. The ability to repel substances is dependent on surface energy. Surface energy is a typical material property used to characterize hydrophobicity and oleophobicity.

Thermal Stability

Some ingress protection vents must also survive the extremely high temperatures (250 °C) associated with the soldering processes used for device assembly. While the device shown in Figure 2 shows an ingress protection vent that is attached to the outer casing of a device, some applications for ingress protection for communication devices require the vent to be integrated into an individual electrical component (e.g. integrated into the microphone or a sensor). This approach allows for more robust device designs, removes potential leak points in adhesive seals to the outer casing, and can thereby further reduce the risk of device failure due to water ingress. But integrating the ingress protection vent into the electrical component requires that the ingress protection material can survive temperatures associate with solder reflow, a process used to attach the electrical component to a circuit board. This solder reflow process often uses temperature in excess of 250°C.

Uses of the PFAS and Assessment of Alternatives

Why Fluoropolymers and other PFAS can uniquely deliver the needed performance

Today, only PFAS based vents can meet the combination of the above-described highly demanding requirements. Polytetrafluoroethlene (PTFE) is the primary material used for vents in communications devices. Additional fluoropolymers and other PFAS listed below in Table 2 are used to construct the finished vent article and provide an enhanced oleophobic surface on the PTFE membrane so that it more effectively repels oils, sweat, cleaning solutions, and other common fluids that can threaten device reliability.

Microporous structure

PTFE is the only known material that has the inherent physical properties listed above and can also be expanded into a thin, strong microporous membrane. All of these in combination deliver the key characteristics necessary for this end use.

Its microstructure facilitates the transmission of air and sound, while effectively repelling water, other fluids and particulates. **It is the unique combination of the properties listed below which have not been identified in any other alternative materials, or combination of materials, that have been investigated by leading vent manufacturers to date.**[98]

The PTFE membrane is engineered with a porous microstructure that enables optimal transmission of air and/or sound. The thinness and specific pore size allows sufficient acoustic transmission.

The transmission properties of the expanded PTFE membrane also enable the vent structure to be air permeable to rapidly equalize pressure changes, protecting sensitive electronics against condensation and minimizing stress on device seals. The combination of small pore size and hydrophobicity enable resistance to wetting with water. The image of an expanded PTFE membrane in Figure 3 shows the complex microscopic pores providing this combination of properties. For a sense of scale, a very fine human hair (30 microns in diameter) would cover the entire field of view in this image.

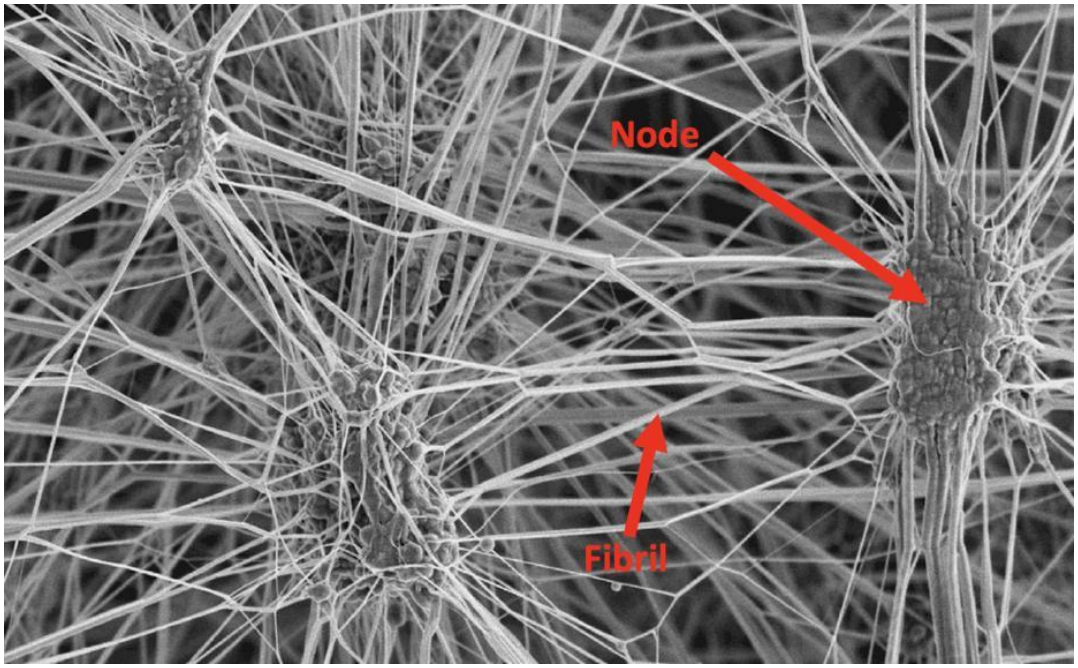


Figure 10 Example of ePTFE Microstructure Showing the Node and Fibril Microstructure

The image above shows a “node and fibril” microstructure which is characteristic of an expanded PTFE membrane. “Fibrils” are the thin fibers, and “nodes” are the solid regions to which the fibrils are connected.

Very few polymers can be processed into microporous structures, and the process used for producing PTFE membranes[99], known as “paste processing and expansion”, is particularly well-suited to creating a wide range of microstructures and thicknesses of membranes not typical of other membrane fabrication processes.

[98] RCOM Ref 4520

[99] This process, known as paste-processing, was first described in US Patent 3,953,566, assigned to W. L. Gore and Associates. The process is also outlined with some detail in “Expanded PTFE Applications Handbook: Technology, Manufacturing and Applications” by Sina Ebnesajjad.

The membrane properties that result from such a process depend on many factors, including the starting polymer properties, the temperature at which the membrane is expanded, and the amount of stretching that is applied during the expansion process. The wide range of process space allows for a wide array of ePTFE membranes to be manufactured through this process. One key attribute of PTFE is that it has a very wide range of temperatures over which it can be stretched (from around room temperature up to in excess of 300°C). The expansion process converts starting polymer particles (called “fine powder”) into “fibrils”, and polymer that is not converted into fibrils remains in “nodes”, resulting in expanded PTFE’s characteristic node and fibril structure in a high porosity form. The node and fibril microstructure of PTFE membranes is well-known[100] to offer a unique combination of air permeability, water resistance, mechanical strength, and acoustic transmission.

The membrane can optionally be laminated with other support materials, coated, or otherwise treated to impart additional properties. For example, the membrane can be treated with additional PFAS in the form of a coating or surface treatment to increase its oleophobicity and contamination resistance, further adding to the unique combination of material properties of the PTFE membrane.

PTFE is the only polymer that has been found to be capable of being commercially produced using the above-described process. Extensive research and development by leading vent manufacturers[101] has not identified any other polymer material which:

- is compatible with paste processing
- can be expanded to produce a microporous membrane
- is available in the fine powder form required for paste processing
- has a wide processing temperature range
- can currently be developed into commercial processes.

Therefore, there are no known alternative membranes with this characteristic microstructure.

Hydrophobicity

Hydrophobicity is the ability a solid material to resist the spreading of water on its surface. Hydrophobicity is a key property for a material which is used to manufacture a membrane to provide ingress protection of communication devices. Membranes made from polymers with hydrophobic polymers resist wetting with water and thereby prevent water entry into devices which can cause failure. The greater the hydrophobicity, the better a mmbrane can resist wetting. The less hydrophobic a material is, the more likely it is that it will fail to resist wetting with water and lead to device failure.

Surface energy is a fundamental measure of hydrophobicity. The lower the surface energy, the more hydrophobic a material is.

Expanded PTFE is naturally hydrophobic and has a surface energy of 19 dynes/cm. This allows it to easily repel fluids with surface tensions above 40 dyne/cm, such as water (72 dynes/cm) and coffee (40 dyne/cm). When treated with an additional fluoropolymer, the surface energy can be further decreased.

[100] US Patent 6512834B1 “Acoustic protective cover assembly”, W. L. Gore and Associates
[101] RCOM Ref 4520

Not all polymers are hydrophobic, and no other polymer as inherently hydrophobic as PTFE can be processed into as broad an array of microstructures as PTFE.

An extension of hydrophobicity is oleophobicity, which requires even lower surface energy, and enables non-wetting properties with lower surface tension fluids and will be discussed later.

Oleophobicity/Contamination Resistance

Oleophobic treated PTFE has a reduced surface energy and can effectively repel fluids with very low surface tensions.

For example, the surface tension of household cleaners range from 27–32 dynes/cm, and the surface tension of isopropanol (a key component of rubbing alchohol) is 22 dynes/cm. If these fluids were to penetrate through a vent during cleaning, they could cause catastrophic damage to electronic components. In the later section detailing alternatives assessment, we will provide specific data that shows that the presence of an oleophobic treatment on a PTFE membrane enables durable water resistance after a vent is exposed to soapy water. Without this treatment, exposure of a communication device to soapy water (e.g. cleaning a device, dropping a cell phone in a sink, vigorously washing one's hands while wearing a smartwatch) could significantly degrade its immersion protection, leading to device failure.

In addition to reducing the ingress of liquids, the oleophobic properties of treated PTFE reduce the wettability of the acoustic vent membrane, so that liquids do not remain on the membrane and degrade acoustic performance or risk clogging the microstructure.

Achieve IP68 Standards

Although the expanded PTFE membrane is extremely thin, its unique structure is engineered to effectively repel debris, water, and other fluids. It also provides ingress protection up to IP68 standards, which represents complete protection from particles and at least 1 meter immersion protection (at a level that is specified by the manufacturer). The membrane has a complex, three-dimensional microstructure which provides a tortuous path through the material. This complex, tortuous path traps very small particles with high efficiency creating an effective barrier to particles of varied sizes. The image below is a scanning electron micrograph of a membrane used for ingress protection for communication devices. The pores in this microstructure are considerably smaller than one micron in diameter, and their complex geometry ensure capture of small particles.

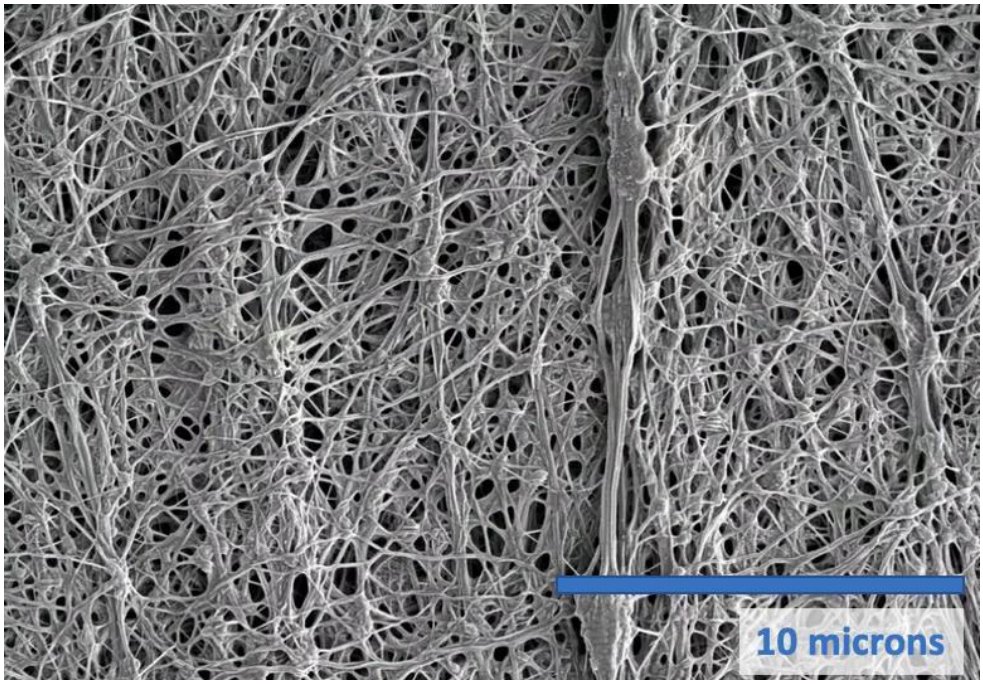


Figure 11 Typical Membrane used in Ingress Protection Vents

In addition to having the appropriate microstructure, the membranes must have sufficient strength to survive the mechanical challenge associated with pressurization. For example, if a membrane is used to protect a device from immersion in 6 meters of water, the water will apply a pressure of 60 kilopascals to the surface of the membrane when under challenge. Under this applied pressure, the membrane must not break or significantly deform in a way that would allow water to enter and damage components, thus causing device failure.

Thermal stability

Many ingress vents must also survive the soldering processes used for device assembly and cope with high temperatures (≥250°C).

PTFE is a very thermally stable polymer, only melting at temperatures well above 300°C, allowing its use in such conditions. Most other polymers that can be made into porous materials cannot survive such temperatures. For example, porous membranes can be made from polyethylene, polyurethane, PVDF, nylon, and polysulfone but all of these polymers start degrading well below 250°C. Two thermally stable polymers that can be made into porous membranes are PEEK (polyether ether ketone) and PI (polyimide). However, they have considerably higher surface energy than PTFE (42 dynes/cm[102] and 44 dynes/cm[103]), and therefore do not have the required hydrophobicity and oleophobicity properties. They are also not compatible with the process used to make PTFE membranes, so they do not offer the characteristic node and fibril microstructure known to be associated with strong performance in this application.

There are no polymers available today that can survive the high temperatures experienced during the component soldering process and can also be engineered to provide

[102] http://www.surface-tension.de/solid-surface-energy.htm, accessed 5/22/2023
[103] https://ntrs.nasa.gov/api/citations/20090026494/downloads/20090026494.pdf, accessed 5/22/2023

microstructure, hydrophobicity, and oleophobicity of a PTFE membrane with an oleophobic treatment. PFAS-based treatments that can be applied to PTFE also can survive such temperatures.

Alternative Materials Referenced in the Restriction Proposal

The Dossier Submitters (DSs) researched the electronics applications of PFAS in detail (as presented in Annex A Table A.1, page 5) and the use of polytetrafluoroethylene (PTFE) is listed in the context of sound-permeable membrane (Restriction Proposal Annex A, Table A.48, page 107). The properties required and provided by PTFE are acknowledged (air permeability, water pressure resistance, liquid repellence and acoustics characteristics).

However, in Annex E of the Restriction Proposal where the derogation and availability of alternatives are discussed, the Dossier Submitters did not assess the need for PFAS in these applications.

Alternatives mentioned by the dossier submitters (DS) in the restriction proposal for the broad category of electronics are not suitable for protection of devices used for communications.

No non-PFAS alternatives are available that would prevent device failure. Alternative non-PFAS materials, and combinations of alternative non-PFAS materials, may be able to replace a singular property, but as discussed in this document, multiple properties are required simultaneously in communication devices. Thus, the only currently viable material is a composite article made from fluoropolymers and other PFAS.

In the analysis of alternatives, the applications described in this document fall within the succinct statement by the DSs that considering *"the inconclusive evidence pointing to the non-existence of technically and economically feasible alternatives at EiF in all other uses, no derogation is proposed"* (Annex E, Table E.131, page 404). The applications described in this document do not appear to have been included in the DS analysis of alternatives for electronics. Considering the broad variety of applications of PFAS in electronics and that the DSs chose to discuss together alternatives covering electronics, semiconductors and even energy sectors (Annex E, section E.2.11.2. from page 389), it remains unclear which alternatives have been considered for PFAS in acoustics vents in communications devices.

In this document, we provide evidence that there are no currently available technically and economically feasible alternatives for ingress protection, and therefore a derogation is warranted.

Assessment of Alternatives

The Dossier submitters identified several materials as potential alternatives for PFAS applications in electronics and semiconductors (Annex E, table E.128, page 396). Not all these materials are relevant to ingress protection for communication devices. We will only discuss technologies which are relevant to the application referenced in this submission.

Non-porous covers (urethane, silicone, PEEK)

Non-porous covers such as urethane, silicone or PEEK can be used to cover apertures when immersion protection is needed with satisfactory sound transmission. However, these materials do not breathe and do not allow for pressure equalization, which is required to alleviate pressure changes that may arise due to typical use (e.g. going up in an elevator or airplane or due to temperature changes), and may in turn also degrade sound transmission. If pressure is not equalized, it will build, applying undue forces to the membrane, device seals, and every other internal component. Such forces will destroy the membrane, break seals, and damage components that are critical to the function and continued survival of the device. **Therefore, non-porous covers are not a viable alternative to ingress protection vents.**

Woven mesh covers

Woven mesh covers can protect an aperture from liquid splash, light spray or rain. However, any dust particles smaller than the defined hole size will pass through these mesh covers because they consist of a single-layer grid and spacing pattern with a defined hole size. Moreover, this alternative will not protect against immersion or aggressive spray. A device which is not robustly protected can allow ingress of dust, which can degrade or induce failure in sensitive components like microphones. A device without protection from immersion is subject to water ingress, which can lead to total device failure. **Therefore, woven mesh covers are not a viable alternative to ingress protection vents.**

Alternate porous membrane

A variety of non-PFAS polymers can be used to fabricate porous membranes, but these cannot be processed to yield the characteristic node and fibril microstructure of expanded PTFE associated with suitable applicability in ingress protection vents for communication devices. These non-PFAS polymers are also not water repellent (do not have low enough surface energy) and so are not viable alternatives for ingress protection vents.

There are several processes that can be used to produce porous membranes from non-PFAS materials. Phase inversion processing is a type of process for making porous membranes by transforming a polymer solution into a solid state in a controlled manner. Electrospinning is a process that uses high voltage to spin fibers from polymer solutions. Track etching is a process that uses nuclear tracks to create pores in polymer films. Sintering is a process which fuses particles of polymer into membranes. The diagrams below show representative examples of membranes made through each of these processes. In each case, it is readily apparent that the membranes have different microstructures than what is shown in Figure 4.

Phase Inverted Membranes

Phase inverted membranes have no presence of node and fibril microstructure. An example of such a membrane is a Polysufone (PES) membrane[104], shown below. **Polysufone is not water repellent because it has surface energy of 47 dynes/cm, which is much too high for use as an ingress protection vent.**

[104] https://www.sigmaaldrich.com/US/en/product/mm/gpwp04700, accessed 5/23/2023

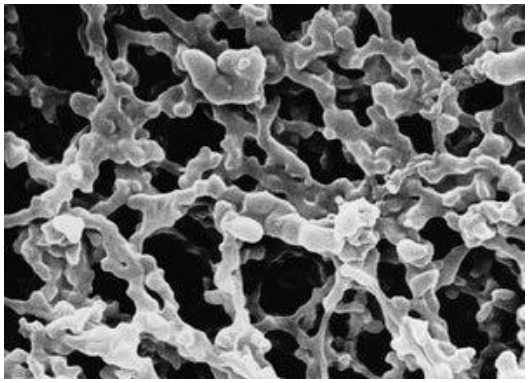


Figure 12 Porous PES

Track Etched Membranes

Track etched membranes do not have a node and fibril structure. An example of this technology, a track etched PET membrane[105], is shown below. **PET is not water repellent because it has a surface energy of 39 dynes/cm, which is too high for use as an ingress protection vent. In addition, these membranes are of low porosity, and offer poor permeability.**

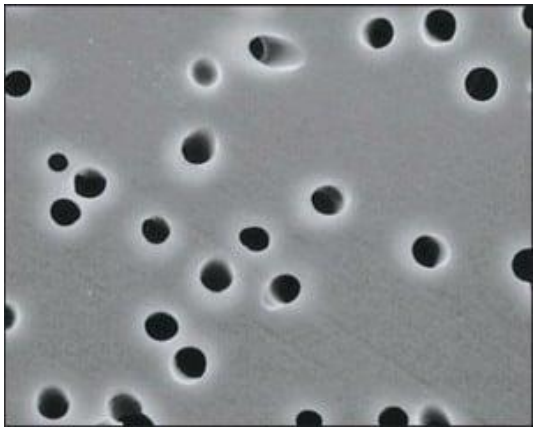


Figure 13 Porous PET

Sintered Polymer Membranes

Sintered polymer membranes do not have a node and fibril microstructure. An example of this type of membrane, a sintered polymer membrane, is shown in the diagram below. **These membranes have a low porosity and are relatively thick. Furthermore, the sintered polymer membranes are not water repellent and are not a viable alternative to ingress protection vents.**

[105]https://www.sterlitech.com/blog/post/etching-the-tracks-in-a-polycarbonate-track-etched-membrane-filter, accessed 5/22/2023.

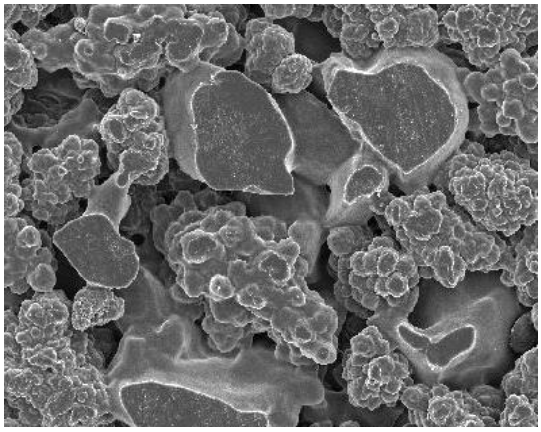


Figure 14 Sintered porous membrane[106]

Electrospun Membranes

Electrospun membranes are comprised of extremely long fibers, which do not have connection points at nodes like in a node and fibril microstructure, as can be seen in the diagram below[107]. Such membranes are also typically characterized by having low cohesive strength. **Electrospun membranes offer some features that may be useful for venting applications for communication devices, but are either comprised of polymers which are not water repellent because they have high surface energy (polyurethane, nylon, e.g.) or they are fluoropolymers (PVDF, e.g.).** One electrospun membrane has been characterized more completely as will be described in the following section.

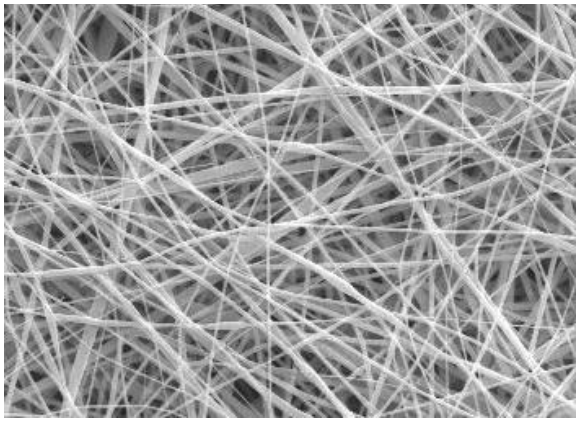


Figure 15 Electrospun Membrane

Polyethylene (PE) and polyurethane (PU)

Two potential membrane technologies which appeared to have some level of hydrophobicity and well-established manufacturability are expanded polyethylene (PE) and electrospun polyurethane (PU). These were selected by a leading vent manufacturer for more thorough evaluation as their property profiles indicated they may possibly be potential candidate

[106] https://www.porex.com/porous-polymers-technology/, accessed 5/22/2023.
[107] http://electrospintech.com/generalcharacteristics.html#.ZGu7EuzMLfs, accessed 5/22/2023.

alternative materials ().[108] As shown in Table 5, samples having average pore sizes similar to current PFAS vent solutions were selected.

Sample Type	Average Pore Size [microns] [109]
Commercial ePTFE + PFAS Coating (GAW342)	0.50
Commercial ePTFE (GAW337)	0.61
ePE Reference #1	0.69
ePE Reference #2	0.43
Electrospun Polyurethane Reference	0.43

Table 9 Membranes Selected for Contamination Resistance Study

These membranes were evaluated for their immersion protection properties when subjected to industry qualification methods which model typical mobile device consumer behavior. As highlighted above, an ingress protection level of IP68 means a total protection from the ingress of dust and continuous immersion in more than 1 meter of water (in agreement with the manufacturer and user) for 30 minutes. In this case, the immersion depth that is relevant for these materials is 6 meters, so that was the depth at which testing was performed.

Table 6 shows survival probability in a water submersion test after exposure[110] to soapy[111] water for each membrane material, which is a typical qualification method for electronic devices. After exposure to 0.01 % soap in water (ten times less concentrated than a standard solution), all candidate alternative materials (ePE and electrospun polyurethane) as well as uncoated ePTFE exhibit a failure rate of 50 % or greater.

All alternative materials and **uncoated ePTFE** exhibit a survival probability near 0 % after exposure to a standard soapy water solution of 0.1 % soap in water. In contrast, more than 80 % of samples made of ePTFE with an additional PFAS coating pass the submersion test after exposure to 0.1 % soapy water.

[108] RCOM Ref 4520
[109] Pore sizes of these membranes were determined via a bubble point measurement on a Quantachrome 3GzH capillary flow porometer, in accordance with ASTM F316-03.
[110] Samples of these flat sheet membranes with a diameter of 1.5mm were prepared, and small droplets of soapy water (20 microliters in volume) were placed on the surface of the parts. Soap solutions were prepared in a range of concentrations (e.g. 0.01% v/v, 0.1% v/v, 1% v/v). The samples were dried in an oven at 60°C for three hours until completely dry. Once dry, samples were pressurized with clean water on the soapy membrane surface at a pressure equivalent to submersion in 6 meters of water (0.6 bar)[110]. If water was passed through the membrane, the time was noted, and the test was marked as a failure.
[111] The soap is a mixture of sodium lauryl sulfate (SDS or SLS), lauramine oxide (LO), sodium chloride (NaCl), and water. The ratio of SLS:LO:Salt is 5:2:3, and the mixture is 80% water by mass.

Sample Type	0.01 % Soap/Water	0.1 % Soap/Water
Commercial ePTFE + PFAS Coating (GAW342)	> 80 %	> 80 %
Commercial ePTFE (GAW337)	< 30 %	~ 0 %
ePE Reference #1	< 20 %	~ 0 %
ePE Reference #2	< 40 %	~ 0 %
Electrospun Polyurethane Reference	~ 50 %	~ 0 %

Table 10 6 meters water submersion survival probability

Despite having comparable average pore size to fluoropolymer based membranes, PE and PU did not show sufficient resistance to wetting after exposure to soapy water.

Only the expanded PTFE membrane with PFAS coating showed acceptable survival in the water immersion challenge after a typical soapy water exposure. This is attributable to its low surface energy, which is a unique property of PFAS materials.

One of the reasons why expanded PE membranes and electrospun PU membranes fail the soapy water test is that these polymer membranes are not as inherently low surface energy as expanded PTFDE, and therefore not as inherently hydrophobic. Polyethylene has a surface energy of 30 dynes/cm, polyurethane has a surface energy of 38 dynes/cm, while PTFE has a surface energy of 19 dynes/cm.

They also do not offer thermal stability comparable to PTFE, which does not melt until temperatures in excess of 300°C. Ultra-high molecular weight PE, the most thermally stable grade of PE, melts at approximately 150 °C, at which point structure and other properties will degrade considerably. Thermal degradation of PU can also begin at temperatures as low as 150 °C[112].

So, while membranes made with these potential alternative materials have some properties similar to PTFE membranes, their level of performance in testing shows that they are not suitable alternatives in their current forms due to fundamental material properties inherent to their chemistry. **Therefore, Polyethylene (PE) and polyurethane (PU) membranes are not viable alternatives to ingress protection vents.**

Other Design Approaches

Alternative design approaches which have been considered are shown below, however **they do not provide ingress protection, and are therefore not viable alternatives.**

[112] https://www.americanchemistry.com/industry-groups/center-for-the-polyurethanes-industry-cpi/resources/library/polyurethanes-and-thermal-degradation-guidance

Alternative Technologies/Design: As the DSs focus essentially on alternative materials, we would like to complement the alternative discussion and present option that requires an alternative technology/design.	**Open apertures** Open apertures provide unimpeded sound, but provide no protection from dust, liquids or immersion. Designs with open apertures are highly susceptible to component failures and decreased device life, so this approach is not a feasible alternative. **Sealed housings** Sealed housings protect electronic devices by providing a barrier against water or dust but prevent pressure and temperature equalization. As the device generates heat or experiences changes in pressure (due to going up in an elevator or an airplane, e.g.), pressure will build inside the housing. These internal pressure changes put significant stress on the housing seals which over time will fail, allowing water and contaminants to enter. This approach has similar downsides to non-porous covers, and neither represents a reasonable alternative.

Table 11 Alternative Design Approaches

Conclusion

For more than 20 years leading material suppliers and device producers have looked for alternative materials and methods for protecting communications devices, but nothing has proven capable of meeting sufficient performance as compared to the PFAS based vents. There has been significant incentive based on the high value and large number of users for this application.

Why a 13.5 year Derogation is Required

The DSs have not specifically assessed the need for fluoropolymers and other PFAS in membranes for ingress protection, as the draft PFAS restriction is currently written, these products would fall under the default transition period of 18 months after EiF. We have demonstrated that no alternative is currently available which meets the performance requirements, and in the following we will illustrate the timeframe needed in the unpredictable case that a new material would be discovered or invented for this application.

Despite the high cost of raw materials[113] and the inherent incentive to find cheaper alternatives, no viable alternative materials have been identified and developed to date for use in communications devices. We, and other key actors in the supply chain, estimate it could take at least another five years to identify and develop possible alternative polymer materials. This first step involves discovery, to which a specific timeline cannot be planned.

[113] The Restriction Dossier refers multiple times to higher costs of fluoropolymers (Annex E, page 285, 390, 444, 458, 504, ...)

Any possible alternative materials will then need further development to optimise them for specific application requirements (e.g., ingress protection and acoustic performance). We estimate that steps within this stage could take more than a year. The ingress protection and acoustic properties of these alternative materials will need to be evaluated to ensure that they provide adequate performance.

The final optimised material will then need to be manufactured into vent components so that reliability testing can be carried out, ultimately leading to creation of a new supply chain for assembly in devices that users may come to rely on.

Steps for substitution	What activities does this step entail?	Time required for step
Discovery	Identify and develop suitable alternative materials. Material and process development from lab discovery to prototype scale. This will involve independent development of membrane and treatment technologies, as well as confirmation of their compatibility.	**Unknown** Estimate 3-5 years for this use
Development	Optimise material for specific application requirements (e.g. ingress protection and acoustic performance). This may involve transitioning processes to pilot scale or small-scale manufacturing.	1-2 years
Certification	Reliability testing of manufactured components, and initial validation of reliability in prototype device and/or representative testing.	1-2 years
Production	Investment, installation, and qualification of new mass production capability. Establishing robust material supply chain.	1-2 years
End Device	Development cycle of new communications device products, including establishing specific performance criteria (ingress protection, acoustic transmission, pressure equalization, etc.) in collaboration with end device manufacturer, developing tooling specific to individual devices, in-house and third party testing, and validation of processes for conversion into parts for installation in devices.	1-2 year
Total		**7-13 years**

Table 12 Estimated Timeline for Substitution

Material use and emissions

The amount of PFAS required for this end use is extremely low - less than 35 kg of PFAS are placed on the market in the EU each year.

We estimate that the total annual number of new smartphones and wearable communication devices sold in the EU with IP68 ingress protection ratings is approximately 172,000,000.

A typical vent for air and/or sound transmission for a smartphone has an estimated diameter of 4 mm (with an inner diameter of 1.6 mm) and the thickness of the fluoropolymer membrane is about 0.007 mm. The typical density of the membrane in smartphone vents is about 0.4 g/cm^3 and a typical smartphone generally has four microphones (two at the bottom of the phone, one at the top of the phone and one on the back of the phone to assist with video recording) and two speakers (one at the bottom of the phone and one at the top of the phone). Therefore, the total amount of PFAS in a typical smartphone due to vents is estimated at about 0.2 mg which results in an estimated total annual weight placed on the market in the EU of about 35 kg per year.

Ingress protection vents are not a significant source of PFAS emissions across their lifecycle

Without a derogation, devices which both the general population and a wide range of professionals (police, emergency medical and fire services, military, transport operators, etc.) rely on for their daily and urgent communications would have an increased failure rate. This will lead to disruption to routine and critical communications and have a significant environmental and financial impacts on EU citizens.

- **Productivity and Safety Impact –** PFAS based vents are critical to the performance and reliability of communications devices which are essential to daily life and work for hundreds of millions of EU citizens. In addition to being important for daily communication and coordination, these devices are also used for critical communication with emergency services (medical, police and fire) and more recently have begun to track and report critical health care data including glucose levels, heart health data, along with automatic car crash and fall detection. A failed device isn't just an inconvenience, it can delay or prevent critical lifesaving services.
- **Environmental Impact** – Management of electronic waste is an important priority. PFAS based mobile device vents prevent device damage, increase product longevity which in turn keeps millions of devices from being disposed each year. When a device prematurely fails, more waste is generated and critical raw materials, energy, and associated greenhouse gas emissions are required to replace these devices creating a greater burden on the environment.
- **Financial Impact** – Without PFAS based vents, the rate of failed devices will increase significantly, creating a significant productivity and financial burden for EU citizens who must invest hundreds of millions of Euros each year on replacement devices. In 2016, it was estimated that 100,000 phones were damaged per day before high levels of Immersion Protection ratings were widespread. Consumers could face a cost increase of greater than 600 euro/device due to replacement of prematurely failed devices, which at an EU level amounts to a cost of more than €20 billion per year.

  There would be an impact to industry as well. Communications devices represent a large and growing industry that generates significant income and supports a large

number of jobs in the EU. Value chain disruptions from restricting a key component for communications devices may therefore significantly impact the EU economy.

Proposed derogation

Paragraph 2(c) shall apply from (**13.5 years** after entry into force) to **PFAS used in ingress protection vents for communication devices**. By (3 years before the derogation is due to expire) the Commission shall review this derogation to assess whether alternatives are now available or whether further renewal of this derogation is needed and publish amendments to the Regulation.

11. Mobile Telecommunication network infrastructure equipment

General summary of the application category

Mobile telecommunication network infrastructure equipment uses high power Radio Frequency (RF) signals to communicate with various mobile devices. For several applications within the RF-signal path the combination of dielectric- and mechanical-properties of materials are essential. This is the case in applications where the wavelength of the signal is of similar length as the physical dimensions of the design.

PFAS in the form of fluoropolymers are today used in radio frequency (RF) related parts of the (B2B) mobile telecom network infrastructure equipment (NIE). For example, Radio Units (which amplify the electrical digital signals to high power RF signals), RF cables and connectors (which connect the Radio Unit with the Antenna) and Antenna parts (that send the signal from the base station to the mobile devices connected with it).

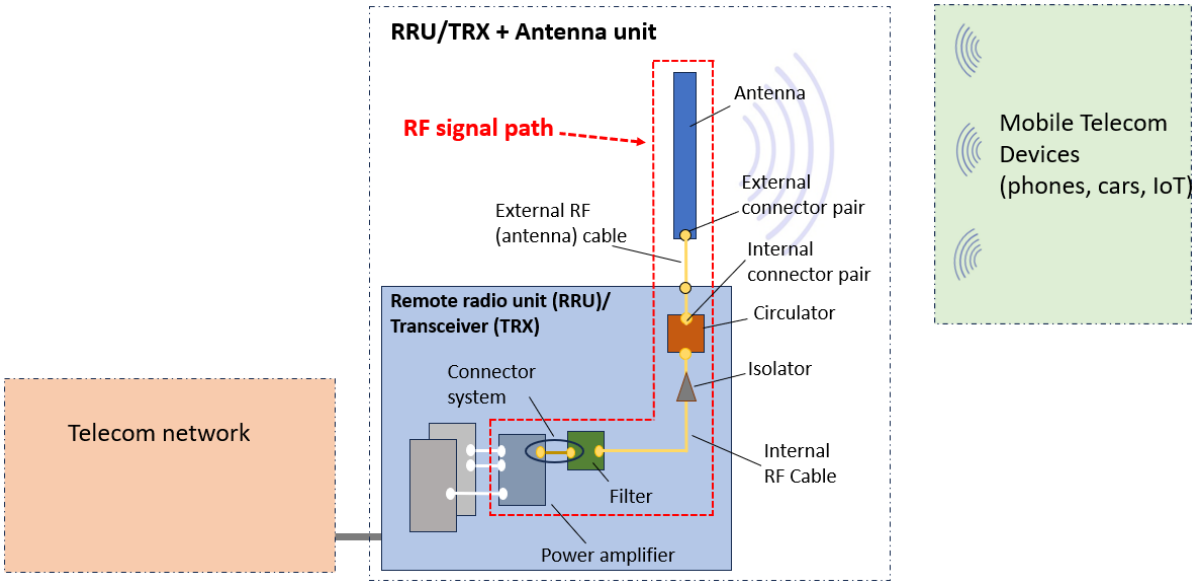


Figure 16 Schematic representation of the wider telecommunication network (left), the mobile telecommunication network infrastructure equipment containing the RF-signal path which via the antenna communicates with mobile devices through electro-magnetic waves.

Reasons for use

The fluoropolymer (e.g. PTFE, PFA) key material properties related to electro-magnetic radio frequency waves are Dissipation factor (or RF loss factor) (Df), Passive Intermodulation (PIM) and Relative permittivity (Dk) which are essential for the performance and energy efficiency of the high power RF signal carrying part of mobile telecom NIE. Fluoropolymers, and primarily PTFE, because of the above properties as well as intrinsic fire retardancy and mechanical properties, have been widely used in the industry as the material of choice for the RF-signal path.

For certain applications within the RF-signal path the combination of low Dk, low Df and low PIM levels are necessary and currently only achievable with fluoropolymer materials. The RF-

signal carrying parts are what are called “transmission lines” where the mechanical dimensions of the design are as important as the electrical design. This implies that whenever alternatives will be provided by polymer producers, all the designs of RF-signal path will need to be reviewed. The RF-signal path is dimensionally designed for the fluoropolymer chosen with its dielectric characteristics. Changing the polymer means changing dielectric properties of the insulator, including the dimensions of the interfaces of coaxial connectors as well as the printed circuit boards in both the radio and antenna part of the system. The performance reduction by switching to materials with higher levels of Dk and/or Df cannot be fully compensated by dimension adaptations. For example, the currently most prevalently used Printed Circuit Boards (PCB) material (FR-4: a glass reinforced epoxy material) cannot come close to meeting these requirements.

The use of fluoropolymers in applications associated with high power radio communication technology (i.e. professional infrastructure equipment with output power and frequencies beyond Bluetooth and Wifi) including radio and television broadcasting is ubiquitous due to the fact that it combines excellent dielectric properties with mechanical properties.

Alternative materials parameter comparison

Features	PTFE	LCP	TPX	PEEK	PEI	PE
Dielectric Constant (Dk)	~2.1	~3.0	~2.2	~3.0	~3.1	~2.3
Dissipation factor (Df)@ 10GHz	<0.001	<0.002	<0.001	<0.003	<0.004	<0.001
PIM (dBc)	-164	-149	-149	-149	-149	-149
Abrasion resistance	++	+	+	++	+	+
Operation temperature	++	+	+	++	+	--
Machinability	++	+	+	+	+	+
Corrosion/Weathering resistance	++	+	+	++	+	+
Price	+	+	--	---	--	--
Manufacturability	- (CNC, Compression Molding)	++ (Injection molding)	++ (Injection molding)	++ (Injection molding)	++ (Injection molding)	++ (Injection molding)

The impact of differences in these properties is significant. Especially when used at frequencies in the 1 to 10 Giga Herz range used for telecommunications. For example, PCBs are used for several different components and applications in passive and active antennas for mobile telecommunication NIE. The electrical requirements and especially the radio frequency parameters and their tolerances are tightly defined and demanding for the materials. Only very special material set-ups for dual- and multilayer PCB realizations can fulfil these requirements.

Standard requirements of antennas for mobile telecommunication

Three main electrical requirements define and determine the material choice for PCBs for mobile telecommunication antennas. One additional aspect is essential for production robustness and acceptable yield:

- high power level (e. g. >= 400 W input power for a single low-band system at 600-900 MHz)
- high efficiency = low losses necessary
- very low level of PIM
- resilience to production processes, e.g. several soldering processes (including subsequent repair if needed)

Requirements for PCB materials

With the requirements for the antennas, it is possible to derive the requirements for the base materials (or substrates) and the general set-up of PCBs:

- losses should be as low as possible (losses generate heat and require higher amplifier power to produce the required output power)
- very low level of PIM
- high level of peel strength of copper foil

A comparison of mean values of losses of typical materials with and without fluoropolymers used in the antenna industry can be seen in fig. 17. With this comparison it can be shown, that fluoropolymer materials have a clear advantage compared to non-PFAS materials due to lower losses which will also reduce heating in components for high power applications.

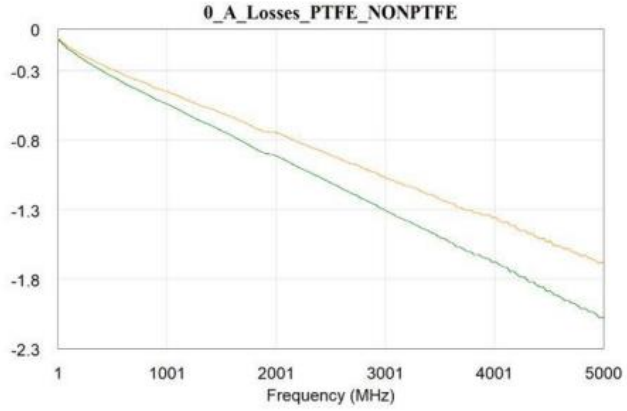


Figure 17 Mean values of losses of typical PTFE- (orange/upper line) and non-PTFE (green/lower line) materials over frequency. Measured with 50 Ohm lines, length of 560 mm. Three typical materials for PTFE and non-PTFE, 20 samples each candidate. Y-scale in dB indicating clearly lower losses of PTFE candidates

In fig. 18 a comparison of mean values of PIM of several typical PTFE- and non PTFE-candidates is made. The PIM performance is far better with PTFE materials and gives sufficient buffer for antenna applications.

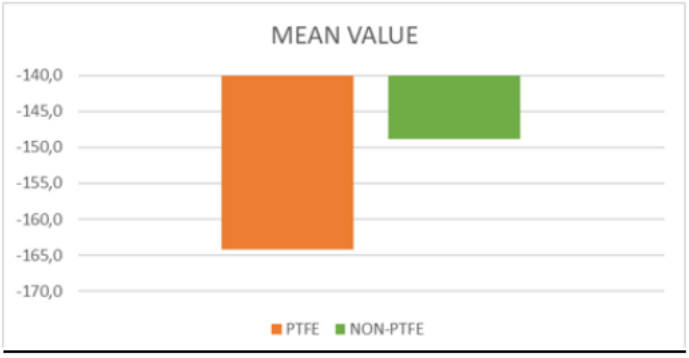


Figure 18 ***Mean values of Passive Intermodulation of typical PTFE- (orange/left) and non-PTFE (green/right) material. Measured with test coupons at 2x20 W at 900 MHz, 1800 MHz and 2600 MHz. Three typical materials for PTFE and non-PTFE, 20 samples each candidate. Y-scale in dBc. As this is a logarithmic scale, the difference of 15 dB in value means that the PIM power is ca 30 times higher for the alternative material, indicating better performance of PTFE materials.***

Process and product robustness and reliability of PCBs is a matter of copper foil peel strength. Higher levels of initial peel strength will better survive several production steps (e.g. sequence of soldering processes) than a low starting level.

Typical peel strength levels for PTFE and non-PTFE materials are between 0,72-0,88 N/mm for non-PTFE and 1,75-2,4 N/mm for PTFE materials. That means, the peel strength for PTFE materials is at least twice of the level of non-PTFE materials. This results in significant higher robustness, yields and life time for components and products using PTFE based PCBs.

These properties play a similar role in all other parts in the RF-signal path such as connectors, cables and filters. Generally the stability of parameters over larger volumes (e.g. lengthy cables) and subsequent batches is critical to the repeatability of the production processes involved.

Exception to the need for fluoropolymers in cables is in certain outdoor antenna cables where in larger diameter cable (from a quarter inch / 6.3mm or larger) where polyethylene foam can be used. This material has a much lower flammability rating which is less of an issue in outdoor cables and is possible due to the larger dimensions both in conductors and dielectric (reducing signal losses to an acceptable level) which in turn reduces the minimum bend radius but allows for lower weight per length of cable.

Explanation of key parameters

- **Relative permittivity (Dk)** (or dielectric constant) is single most important parameter to describe electrical behavior of a certain material. Repeatability of Dk and tight tolerances are necessary for high requirements and quality. Combination of low Dk and Df are necessary for certain high power and low-PIM applications. Currently only PTFE meets these requirements. Non-PTFE materials with low Dk values have higher Df values = higher level of heating of systems and lower efficiency. Relative permittivity - Wikipedia
- **Dissipation factor (Df)** (or Radio Frequency loss factor) **=** Parameter for electrical losses in the material, defines the efficiency of the system. High efficiency means lower waste of energy during operation and less internal heating of system. Internal heating causes problems with electronical and mechanical components and reduces lifetime/robustness/reliability of system in general. Dissipation factor - Wikipedia
- **Passive Intermodulation (PIM) =** Passive Intermodulation (PIM) is a nonlinearity inherent in electrical components that distorts the transmitted signal, causing lower signal quality as well as additional out-of-band emissions. These types of non-linearity are very difficult to compensate and can degrade the sensitivity of the receiver causing loss of coverage. Passive Intermodulation (PIM) -Wikipedia

Interdependencies

Since connectors are used as interface between the components of the RF-signal path (see Fig. 16): **Radio** (board mounted connector) / (cable mounted connector) **cable** (cable mounted connector) / (board mounted connector) **antenna** any dimensional change in either connector or cable will affect the whole design of the RF-signal path.

Connector dimensions are highly standardized and a change in dimensions will require time to develop new standards to ensure various brands can be used without introducing reliability issues. Any change of materials (if at all possible) will require qualification of all materials involved, redesign of the whole product and reliability testing as well as conformity testing to ensure all essential requirements are met both at material level and at system level. Since

viable PFAS-free drop-in alternatives for the uses described above are not available today, many years are needed to identify, qualify and design-in substitute materials.

Additionally, there is significant raw material and supply chain infrastructure dedicated to testing and acquiring PFAS materials that will have to be reorganized and run-in to use alternative materials, either with current vendors or new vendors that will have to be vetted and on-boarded.

Substitution timeline

(Example for implementing a substitute in one model radio printed circuit board (PCB)):

1. **Identify potential substitutes** (2-3 years minimum as no alternatives are on the horizon according to material suppliers)
2. **Qualify substitutes** at material level, assembly level & initial reliability testing (1-2 years)
3. **Develop PCB**, produce & qualify samples of the PCB- assembly (2 year)
4. **Develop system enclosure**, test & qualify at system level (1-2 years)
5. **Conformity testing**: Initiate and pass 3rd party conformity testing (1 year)
6. **Production ramp up:** Start-up of volume production from material vendors through to final product assembly (1 year)

Assuming that each step is successful, the **best-case scenario** for substituting the PCB material in one radio will take 8 to 10 years to complete. The engineers that need to do this work are currently the ones working on the development of the next generation (more circular, more energy efficient) 5G equipment as well as 6G equipment. In order to build a PFAS free Mobile Communications site at least the radio, connectors, cable and antenna would need to pass system level conformity testing – and this would be for just one model.

Multiple models are needed to build an efficient communications network. Once the substitute material initial application is a success, the substitution in other models can build on that and will take less time. However, 12 years at minimum will be required to complete the substitution in the portfolio if no barriers are encountered.

For spare parts none of the above is viable since the product dimensions are set – and cannot change unless a 100% compatible material is found.

Emissions

Emissions to the environment are not expected during the lifetime of the article. Under normal conditions of use the materials are not exposed to mechanical wear and tear and as there are no volatile PFAS components, no emission are to be expected during the lifetime of a product.

The main potential emissions will be generated during manufacturing (production waste) and during the waste phase. Both production and end of life ewaste are managed and treated in a controlled fashion. as electronic waste (not from private households) and will be handled and disposed of according to, at minimum, the requirements of the EU WEEE Directive.

Proposed derogations:

Paragraph 2(c) shall apply from (**13.5 years** after entry into force) to PFAS used **for fluoropolymers meeting the PFAS definition in radio frequency related parts of mobile telecommunication network infrastructure equipment**. **The European Commission shall review this derogation by 3 years before its expiry to assess whether alternatives are now available or whether further renewal is needed and to publish amendments to the Regulation.**

An exemption for fluoropolymers used in spare parts for radio frequency related parts of mobile telecommunication Radio Access equipment.

Environmental impacts and emissions

The quantity of fluoropolymers that are introduced in the EEA in Mobile Telecom Radio Access Equipment (Remote Radio Unit (RRU) or Transceiver (TRX) + Antenna system including all parts in the RF signal path) based on averages over the various types of products (such as single/multiple frequency band, passive or active antenna) and the anticipated market in the EEA for such equipment is estimated at 277.5 ton per year (industry total). (Low estimate: 225.8t /y; High estimate 340.9t)[114]. As the uses described above may not be included in table 1 of the ANNEX XV RESTRICTION REPORT – Per- and polyfluoroalkyl substances (PFASs).

This volume is likely to decrease over time as future equipment designs continue to result in next generation products that are more efficient as regards to the amount of materials used and any substitutes that are identified will be implemented.

With respect to spare parts the quantities are negligible 1) due to the very high reliability nature of telecommunication network equipment failure rates are very low over the normal lifetime of products and 2) failures that do occur in most cases are caused by failing electronic components on the PCB assembly. The PCB assembly is usually repaired by replacing the defect component and subsequently utilized in future repairs. While failure of the PCB itself or associated connectors and cables is rare it cannot be ruled out and replacement parts must be available during the agreed lifetime of the product.

Socio-economic impact

It is difficult for the telecom network equipment manufacturers to estimate the socio-economic impact of replacing fluoropolymers as far as equipment pricing because there are no clear replacement solutions identified and while extensive research and development efforts are required the costs to citizens are unlikely to be prohibitive.

An uncontrolled phase out of fluoropolymers, without any alternatives with similar performance, would increase signal loss and RF output power (increased Df and Dk values), leading to higher energy use, while at the same time the signal quality would deteriorate (worse PIM levels). Further, fire resistance would need to be achieved with intentionally added flame retardants; material properties could not be guaranteed during the entire life cycle (10-20 years) resulting in reduced product lifetime; and high operational temperatures would be challenging for non-fluoropolymer materials. Further, fluoropolymers show good performance

[114] Based on product analysis data and EEA market share assumptions for the industry; details in the confidential annex

in the production processes (high soldering temperatures), where alternatives would lead to higher scrap levels during production. Lastly, since the material characteristics are important for the overall design of the equipment, an immediate change to non-fluoropolymer materials cannot be performed. Hence, sub-optimal substitution may affect both industry and consumers.

Consequently, the whole product needs to be redesigned, tested and qualified, which takes a long time. Hence, there would be a risk that telecommunication infrastructure equipment could not be placed on the market for a period after the entry into force and transition period of the restriction.

The additional time requested will, however, minimize unnecessary market and supply chain disruptions in the sector, prevent a delay of roll-out and upgrading of current mobile communication networks. Socioeconomic impacts linked to a delay in mobile network evolution will include reduced economic growth and reduced access to mobile digital services for all end-users.

As substitutes for fluoropolymers when implemented in new product designs will change the form factors of the products the provision of spare parts for the repair of current network elements is impossible without a specific derogation for repair. Without that derogation, mobile network operators will struggle to consistently provide consistent mobile telecom services even if substitution for new products would be achieved.

Dependable mobile network services are critical to the functioning of modern society.

Notes:

1. The details of the specific PFAS (fluoropolymer) applications as well as issues identified with substitution may vary between companies and therefore cannot be disclosed publicly. More details can be provided by each individual company.
2. Relevant manufacturers of the above-mentioned coaxial connectors plan to submit an industry wide request for derogation that would outline their efforts to identify and suggest alternative materials.
3. Similarly, relevant manufacturers of the above-mentioned Printed Circuit Board materials plan to submit a request for derogation that would outline their efforts to identify and suggest alternative materials.