PFAS and Electrical Connectors

Annex to the ZVEI comments on the UPPFAS Restriction and el. Connectors

1 ZVEI association

ZVEI e. V., the German Electro and Digital Industry Association, represents an industry with an annual turnover of about 225 bn. Euro and 906 thousand employees in 2022.

2 Relevance in EU and Germany

Connectors are the base for an increasingly electrified and digitalized world. They are the key to the possibility of connecting networks and provide electrical and electronic connections. They are used in all electrical and electronics areas. The variety goes from miniature to large, heavy connectors.
Basically, a connector is a physical connection component and is needed to separate and connect lines or enables systems and components to be connected to transmit electrical power, signals and data. Especially in harsh environments with different kinds of dirt, shock and vibration, the physical connection is used and needed. Connectors are required for various use cases as power transmission from 5V up to more than 800V and several hundred Amps. Connectors are the connection backbone from power plant to the microcomputer. Depending on the place of use and the required transmission quality, connectors are designed in such a way that they fulfil the intended purpose or the targeted application in the best possible way. This is in view of technical conditions and economic requirements, rational manufacturing and processing methods, adaptations to existing and future technologies, environmental and economic conditions, permanently increasing data transmission rates as well as higher performance and reliability. To ensure that these demands are met, the connectors are designed for a wide range of requirements and applications.
The market for connectors has developed continuously for years. Growth rates have risen moderately but consistently in established use cases and increasing strongly in new application fields like e-mobility, renewable energies and data operations. Weaker economic developments have also affected the connector industry but have been well absorbed due to the structurally solid basis and the strategic-technological orientation. In addition, the trends of electrification and digitalization with the result of increasing use of sensors and their coupling to systems are inevitably resulting in increased use of electrical connection technology.

Table: Development of the market for electrical connectors (ZVEI internal survey)

Connector market by region	2019 Mio Euro	2020 Mio Euro	2021 Mio Euro	2022 Mio Euro	2023 E Mio Euro
America	9852	9129	10196	11477	12158
EMEA	8647	7749	8453	9195	9559
Japan	6169	5807	6279	7033	7242
Asia/Pacific	18953	18604	21155	24156	25350
Total	**43621**	**41289**	**46082**	**51861**	**54308**

Table: Development of the market for electrical connectors (ZVEI internal survey)

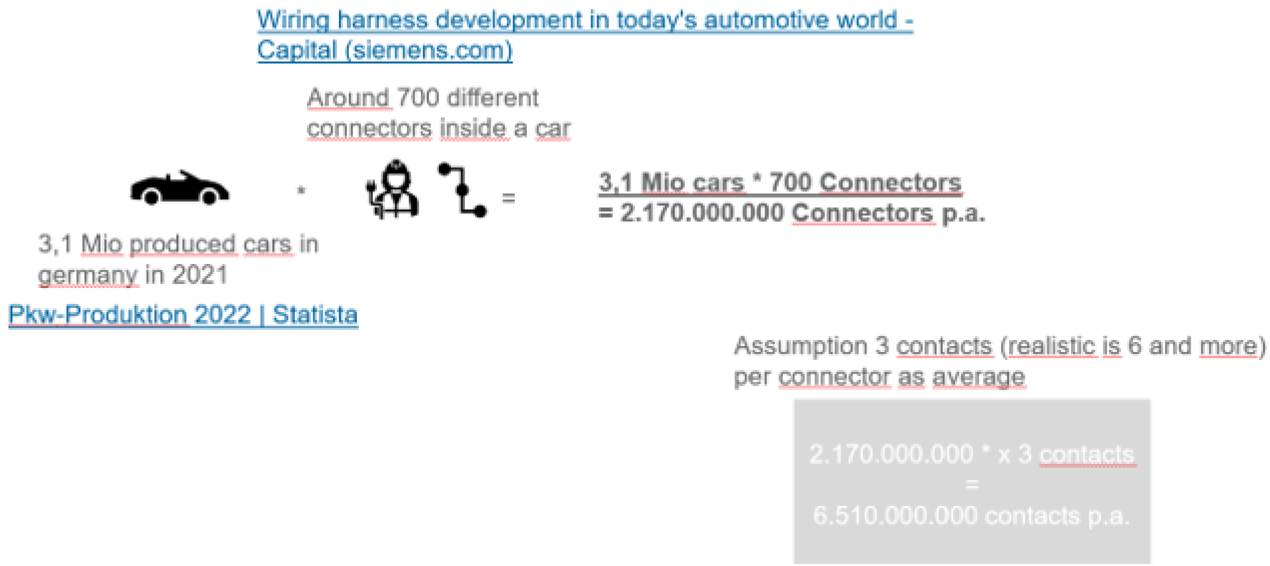

Figure: 1 Connector Volume p.a.- Source: M. Rueter

3 PFAS containing Articles and Substances in electrical Interconnections

a. Lubrication and Contact Wetting

1) Purpose for use

Since no contact surface is perfectly smooth, thinly applied contact lubricants fill in existing irregularities, not only improving contact and electrical performance, but also extending service life by reducing hot spots during current transfer and abrasion.

By filling the air gaps between contacts, contact lubricants provide a critical increase in actual surface area, which in turn prevents local current leakage and the associated temperature rise and resulting oxide formation. Contact lubricants form a barrier to airborne contaminants and reduce frictional effects by providing fluidity of motion. Only by using contact lubricants can multipole connectors be reliably mated or unmated by hand.

If the surface contact is insufficient, the current is only transported over a small part of the surface, resulting in strong heating at the contact points where the surface oxidizes and increases the contact resistance. Regardless of whether they are static or dynamic, mechanical wear occurs on metal interfaces. With static contacts, abrasion occurs due to minimal movement of the contacts caused by vibration, temperature changes. When the surfaces rub against each other, metal particles brake off from the tips and bore through the coated surfaces. This exposes the surface itself and the underlying metal to oxidation and wear. In addition, the detached metal particles can cause interference with current transmission and switch failure.

Industrial contacts are used at temperatures up to approx. 120°C, so local temperatures at the contact points are increased again due to contact resistance. For reliable lubrication of the contacts at temperatures >130°C, only PFPE-based contact lubricants are currently available. In addition, industrial connectors are frequently used in harsh ambient conditions in corrosive atmospheres, so that the contact lubricants must additionally be resistant to corrosive media, which likewise only synthetic lubricants have so far ensured.

2) Function of PFAS content

The lubrication of different friction partners in electrical applications fulfils various functions. Basically, it serves to optimise friction between different material pairings. These can be plastics, metals or both combined. On the one hand, plugging forces are reduced, the frequency of plugging and unplugging cycles is increased, fretting corrosion is avoided or, in general, the stucking of moving elements is prevented.

Lubricants containing PFAS are used to guarantee the above-mentioned properties under the various temperature conditions (actuation temperatures with high minus and plus degrees; actuations after reflow soldering process 260 C) that prevail in the applications and also after several years of ageing. Another reason is the material compatibility in relation to the various metals and plastics used in connectors.

3) Service time over Product lifetime

Under normal condition no service or additional wetting is required

b. Fluor elastomeric sealing

1) Purpose for use

Connectors for non-office applications need in many cases high IP protection for error-free operation. For this requirement O-Rings or custom designed sealings are used to keep the electrical contacts from being contaminated with liquids, chemicals, dust and protect the connector against short circuits and therefore ensures secured electrical operation.

In case of IP protected connectors in environments with an extended temperature range and aggressive chemicals fluor elastomeric polymers like FKM, FFKM, FEPM, FEP, PFA and PTFE offer superior material properties. The fluor elastomeric sealings also provide excellent performance over the lifetime of the entire connector. The design of the sealing and therefore the entire connection is in many cases directly related to the material properties which are used for those sealings.

2) Function of PFAS content

Electronic connectors are used in various applications, therefore they must withstand different external influences. Fluor elastomeric sealing materials like FKM, FFKM, FEPM, FEP, PFA und PTFE provide excellent material properties like

- wide temperature range (-30 to +200 °C)
- resistance to different organic solvents, acids and bases
- UV and Ozon resistance
- Durability and Longevity over lifetime

3) Service time over Product lifetime

Connectors with integrated sealings do not require service over lifetime.

c. PFAS containing Membranes for Pressure Release in Connector Housings

1) Purpose for use

The following described application is a specific application of technical fibres for the use in EEE – but also on part level e.g. sensor or connector.

The membranes are typically used for sealed applications within EEE applications.

In a connector the membrane design elements are typically based on fluoropolymers (e.g., PTFE, ePTFE, etc.) and are used to prevent the penetration of humidity into the product and at the same time to allow some gaseous media to escape to the environment to avoid under- or overpressure inside the product or to enable gas exchange into defined areas of Electronic Equipment for measuring of gas concentrations.

In case of harsh temperature change between ambient and ECU the thereon related vacuum can lead to suction of wetting water on the ECU-housing. The water based liquid film inside the ECU or electronic application may then lead over lifetime to an electric failure of the EEE-application based on electrochemical migration.

Beside this quality related function of the membranes, they are also required in e.g. motor engine ECU's as they need to measure continuously the current ambient pressure to ensure a correct functioning of the engine. As the sensor is an internal element of the ECU, a sufficient pressure equalization of ECU- and ambient-pressure must be ensured. This is particularly important to comply with the high requirements for exhaust gas control.

The over years developed state-of-the-art technical solution that yields acceptable device sizes and function is an application of a porous membrane that compensates the pressure of the ambient and inside the control unit while blocking harmful media. The only known membrane materials that overall fulfil the requirements of media robustness, sufficient air flow rate and high-temperature stability are expanded Polytetrafluoroethylenes (ePTFE) which are a subset of the PFAS-group.

We note that all membranes used in our applications are mainly based on fluoropolymers that fulfil the OECD criteria of "polymers of low concern".

For some specific applications an additional PFAS is applied to achieve certain technical properties. The amount of this additional e.g. coating is very low in an area of a few percentages.

Conclusion:
There are typically no or very few additional design elements required to achieve the required functions.

This results in a high degree of design freedom at the EEE application level, but especially also in the final application, e.g. in the vehicle.

The membrane/vent is based on PFAS and is a very efficient key element in ensuring the safe functioning of the EEE and the applications associated with it.

2) Function of PFAS content

The membranes are typically used for sealed applications.

Fluoropolymers are essential materials for ensuring the required media and high-temperature robustness for above mentioned applications, e.g. by housing ventilation in various components

The unique properties of fluoropolymers regarding the chemical resistance against media (e.g. bad fuels, oil liquids, greases, water solutions, Li-Ion battery electrolyte, DEF, exhaust gas, etc.) in combination with high temperatures in an area of 150 °C are key criteria to achieve the required performance function.

Other special requirements that the used materials must meet are:

- - Both hydrophobicity and lipophobicity for water- and oil-repellency
- - High gas permeation of thin membrane
- - Low swelling in media and humidity uptake
- - Low ion elution in case of e.g., fuel cell applications
- - High lifetime
- - media resistance e.g. as mentioned in the non-exhaustive listing below,
  - Both hydrophobicity and lipophobicity for water- and oil-repellency
  - High gas permeation of thin membrane
  - Low swelling in media and humidity uptake
  - Low ion elution in case of e.g., fuel cell applications
  - High lifetime
  - media resistance e.g. as mentioned in the non-exhaustive listing below,

3) Service time over Product lifetime

We do not have quantitative data on emissions of PFAS from the use phase because they are used as components within a wide range of end-products by different end-users. However, we believe that emissions during their use phase are negligible.

In larger quantities, mainly the fluoropolymers PTFE is used in venting products. According to our information, for these fluoropolymers neither the release of relevant quantities of non-polymeric residuals nor the release of degradation products during the use phase is to be expected for the following reason:

Fluoropolymers are specifically used in venting applications because they do not react, degrade, or erode, even when exposed to aggressive chemicals or relevant application temperatures.

We therefore believe that it is very unlikely that relevant amounts of PFASs here mainly PTFE will be released into the environment from the products during the use phase.

d. PFAS containing Potting Materials

1) Purpose for use

The primary purpose of using Fluor elastomer potting materials is to provide a protective barrier around sensitive connection components, circuits, and devices. This encapsulation shields the internal components from environmental factors such as moisture, dust, chemicals, and mechanical stress in industrial environments. PFAS containing potting materials are realising an extension of life of connections and connectors in harsh environments. Further most of potential substitutes are based on containing silicon materials which are exhale silicon particles. These particles are creating problems in many different applications such as automatic painting and color coating. Automobile production can be mentioned here, especially painting with the hart requirement of “silicon freeness” (Keyword: substances that interfere with paint wetting).

2) Function of PFAS content

Increasing the resistance against high temperature, Mineral oils; increasing aging resistance.
PFAS-containing potting materials act as a chemical barrier, preventing corrosive substances, solvents, and other chemicals from reaching and damaging the enclosed contacts, connections and electronics. The offer of good thermal stability and heat resistance, helping to dissipate heat generated by electronic components and maintain optimum operating temperatures. PFAS-containing potting materials promote strong adhesion to various substrates to be resistant against chemicals such as:
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- water based liquids
- gasoline / petrol super
- diesel fuel
- Biodiesel
- engine oil
- brake fluid
- preservatives (car wax, polishes, …)
- battery acid
- antifreeze fluid
- windscreen washer fluid
- cold cleaning agent
- exhaust gas
- ammonia related gas
- Dust
- Sand

and ensure that the potting material adheres securely to the components and the surrounding housing. PFAS-containing potting materials can provide non-stick properties, making it easier to remove components from molds during the encapsulation process.

e. PFAS containing Anti Dripping additives

1) Purpose for use

Polytetrafluorethylen (PTFE) finds widespread use as flame retardant synergist for polycarbonates (PC), acrylic butadiene styrene copolymer (ABS) and polybutylene terephthalate (PBT) to prevent a melt-drip of polymers in fire, as burning drips can spread the fire. PTFE acts as anti-dripping additive and is necessary for the material to attain UL 94 V-0 classification. Due to their good mechanical and insulating properties, polycarbonates and PBTs find frequent application in electrical connectors, for example as strain relief. They operate in close proximity to currents and as such are subject to rigorous safety standards concerning flammability. European technical standards for fire safety requirements are for example IEC 60898 for circuit breakers, IEC 60947 for industrial control equipment or IEC 60335 for the area of domestic appliances determined from the International Electrotechnical Commission (IEC). Furthermore, technical standards of the American Underwriters Laboratories (UL) have been adopted in Europe and Asia as well. Therefore, the American UL 94 V-ratings are also internationally known and used flammability requirement.

2) Function of PFAS content

PTFE usually makes up a small amount of the material (≤0.9% of total composition) and complements the flame retarding system. The mode of action is described as a "physical effect of microfibrils formed during processing which shrink back under fire, preventing dripping release" in case of polyamides.(1) For polycarbonate and ABS, rheological effects of reduced viscosity and induction of a flow limit ("solid-like behaviour at low shear stresses below a yield point") are discussed in literature.(2)(3) Since the main (flame retarding) component BDP functions as a plasticizer for PC/ABS, the benefits of flame retardation are negated by the decreased viscosity which promotes dripping. The addition of PTFE as synergist is necessary to compensate for this effect, allowing the material to fulfil the flammability standard according to UL94 V-0. The anti-dripping flame retardance provides a higher amount of safety and security to end-users, greatly reducing the likelihood of a thermal event and PTFE provides a critical anti-dripping property to flame retarded grade polymer resins, this prevents melt-dripping in fire event in finished goods.

(1) Diniz, A. T. S. et al. (2023) 'High heat resistance can be deceiving: Dripping behavior of polyamide 4.6 in Fire', Macromolecular Materials and Engineering [Preprint]. doi:10.1002/mame.202300091.
(2) Matzen, M. et al. (2015) 'Influence of flame retardants on the melt dripping behaviour of thermoplastic polymers', Materials, 8(9), pp. 5621–5646. doi:10.3390/ma8095267.
(3) Schartel, B. (2010) 'Phosphorus-based flame retardancy mechanisms—old hat or a starting point for future development?', Materials, 3(10), pp. 4710–4745. doi:10.3390/ma3104710.

3) Service time over Product lifetime

Articles don't require service and remain in product over lifetime.

4 Qualification Timeline for New Product -(alternatives)

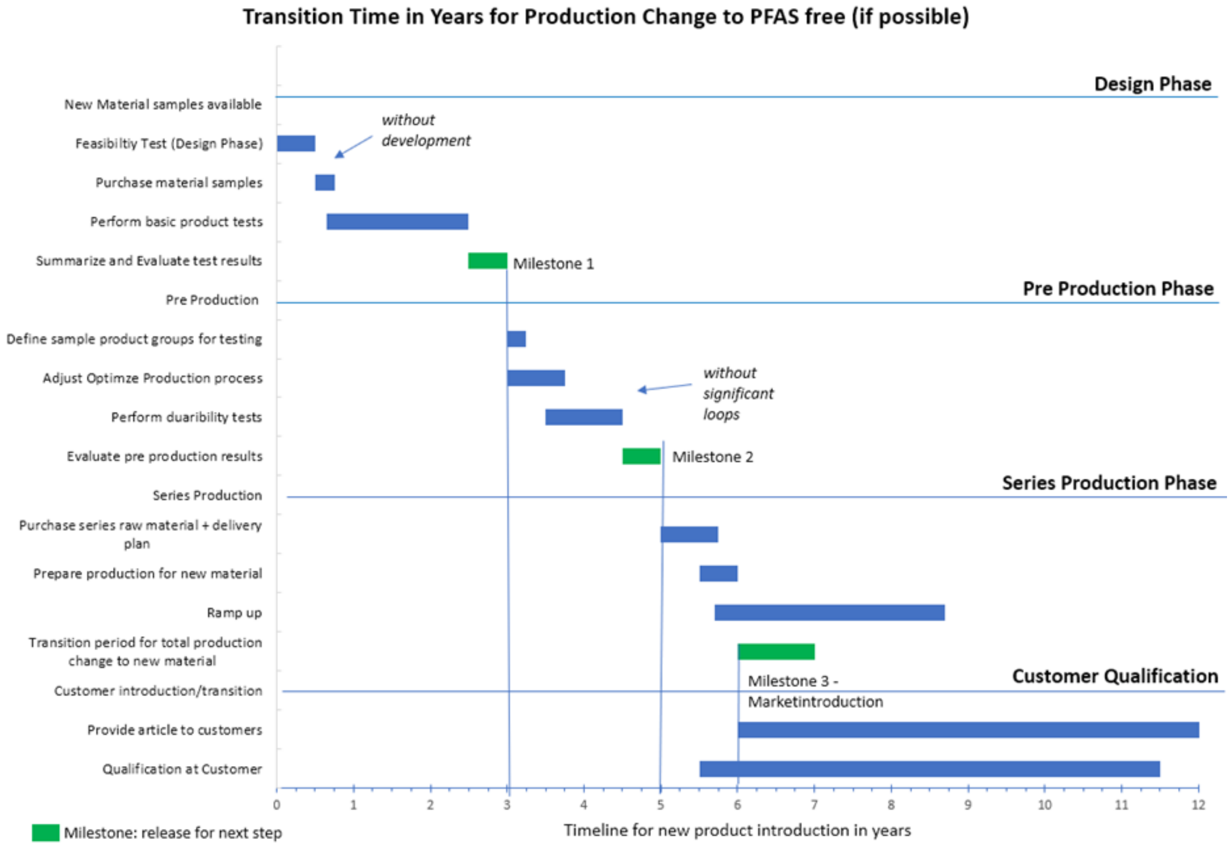

Figure: 2: Timeline for New Product Introduction – Source: A. Schier

The qualification phase can only start if materials have been identified that meet the basic requirements. Based on these results connector sample designs need to be developed and qualified for the suitable function in typical applications. Based on these experiences the design phase 1 transitions into design phase 2 under pre series conditions to evaluate and optimize the manufacturing process, which will lead to investigations under series conditions in design phase 3. For phase 3 tools and machines need to be purchased and set up to finalize PPAP under series conditions and to be confident of a stable process.

Assuming that prequalification with test samples can be performed within one year the transition time to series production will take further three to four years to have production under series conditions. After market availability under series conditions the new products need to be tested and accepted by the customers. Depending on the applications the connectors need to be approved for the final applications which could take up years in critical type approved applications like transportation or products in scope of radiation protection regulations.

5 Effort escalation due to new development and upstream due to unavailability and performance losses

High effort for tests and product-documentations. See also Qualification Timeline

We are not able to provide a cost estimate. . However, it is important to note that evaluations of alternative materials have shown that, where available, they often do not meet the required performance characteristics of PFAS and lack the range of properties required for electronic and semiconductor applications, such as high chemical and thermal resistance..
The proposed restriction will result in increased costs and reduced productivity, both in the performance of the product applications and in their use, creating an additional burden for customers, potentially limiting their choice, and reducing the incentives for technological advancement.

Products manufactured with alternatives having lower durability and reliability would also result in higher maintenance and replacement frequency and eventually increased waste.

Assuming that alternatives are already available, which is not the case will undoubtedly lead to sudden supply disruptions.

The supply chain problems based on Corona as an example had already caused difficulties in recent years resulting in shortages across numerous economic sectors and major societal effects.

Supply disruptions have threatened e.g., the semiconductor industries, not only in the automotive sector but also in the consumer electronics sector. It shows very clearly the case that if one part or material suddenly disappears within the supply chain the complete thereon based production stops up to the final product e.g., automotive.

The proposed restriction has the potential to lead again to a crisis in the supply chain, but this time not “limited” to the semiconductor but extend to a very broad ranges of supplies like mechanic parts, electronic parts, chemicals….

The risk for shortages based on this PFAS-restriction is therefore very much higher.

6 PFAS Waste treatment

The typical process of end-of-life treatment depends on the related use sector. In e.g. automotive related applications, the first step is dismantling of specific parts of interest or as defined by specific regulations e.g. End of life vehicle directive -ELV (2000/53/EC). EEE typically remains because of their small size and mounting position in the car.

Electrical connectors are typically part of electrical goods in scope of the WEEE directive (2012/19/EC) or other regulated markets. Hence the transition from the use phase to waste is well defined in a way that uncontrolled disposal is unlikely.

Most of the technically used PFAS are long time stable and very resistant to chemicals. PFAS waste treatment technologies are mostly investigated and technically evaluated by energy assisted technologies. In case of polymeric PFAS, incineration technologies were investigated with PTFE waste.
Under test conditions in a waste incineration chamber, with a setup in compliance to the requirements of the 17th BImSchV, it was demonstrated that polytetrafluoroethylene (PTFE) can be almost fully transformed into fluoride (F^-) (as hydrofluoric acid (HF)). Samples of the flue gas were analysed for the presence of 31 PFAS and found to be without significant measurable PFAS content. (1)

At temperatures above 750°C PTFE decomposed to C2F4 and C3F6 in a pyrolysis process. During further combustion CF4 will be generated. At combustion temperatures above 1000°C CF4 formation is much reduced. (2)

Based on this result a municipal incineration system according to the requirements according to §8 of the 17.th BImSchV (3) was sufficient to not detect any PFAS in the flue gas with exception of greenhouse gases like CF4 or C2F6 but with low evidence due to weak database. Technologies for CF4 decompositions are in operation and development with focus on semiconductor processes. A system for incineration of hazardous waste operates at about 200°C higher combustion temperature.

A test facility for incineration of production PFAS waste was setup in Cooperation with the “Deutsche Bundesstiftung Umwelt” and company Dyneon. This facility is able to decompose more than 90% into its monomers. (4)

Other test facilities investigated the incineration of PFOA treated fibers and observed decomposition at 1000°C without chromatographically detectable PFAS in the flue gas. (5)
In a literature study PFOA and PFOS decomposition was successfully investigated at 350°C in supercritical water. (6)

Incineration of Perfluoropolyether (PFPE) are less investigated but during development of PFPE fluids was observed that these fluids become instable at temperature above 290°C (7)

Other incineration systems for PFPE operate at 330°C with metallic iron reactants like aluminum powder for binding decomposed PFPE. (8)

For treatment of radioactive PFPE lubricants an incineration system with MnO2-catalyst and N12CO3 immobilizer was successfully tested (9)

(1) Krasimir Aleksandrow, et. al; “Waste incineration of Polytetrafluoroethylene (PTFE) to evaluate potential formation of per- and Poly-Fluorinated Alkyl Substances (PFAS) in flue gas“; Elsevier Chemosphere 226, p898-906; 2019
(2) Sandra Huber, et. Al.; “Emissions from incineration of fluoropolymer materials”; Researchgate OR 12/2009
(3) 17. BImSchV
(4) Press Release “Pilotprojekt: Recycling von Fluorpolymeren”; Universität Bayreuth; Lehrstuhl für Werkstoffverarbeitung
(5) Takahoro, Yamadam et. al.; “Thermal degradation of fluorotelomer treated articles and related materials” Elsevier Chemosphere Vol 61, Issue 7 p974-984; 2005
(6) Sanny Verma, et. Al.; “Recent advances on PFAS degradation via thermal and nonthermal methods” Chemical Engineering Journal Advances; Elsevier Marc. 2023
(7) William R. Jones, et. Al.; “Thermal Oxidative Degradation Reactions of Linear Perfluoroalkyl Ethers”; II Symposium on Fluorpolymers; 183rd National Meeting of the American Chemical Society; 1982;
(8) Mimi Y. Keating, et. Al.; “Decomposition of perfluoropolyether lubricants” Journal of Thermal Analysis and Calorimetry 106; p213-220; 2011
(9) XinHang Du, et. Al.; “An efficient approach for the treatment of radioactive waste perfluoropolyether lubricants via a synergistic effect of thermal catalysis and immobilization”; Journal of Environmental Sciences, Vol 136, p512-522; 2024

7 Exemption request

We are requesting an exemption for electrical connectors for a period of 12 years plus a reasonable transition period of at least 4 years for all types of electrical connectors.

In addition, it must be possible to apply for a further derogation in case no suitable alternative is available on the market. The exemption methodology should be in line with the current RoHS Directive.

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