

W. L. Gore & Associates' Comments on Dossier Submitters' Draft EU REACH restriction on PFAS

Public consultation

Request for Derogation: Aerospace and Defence

July 2023



Gore appreciates the opportunity offered by the public consultation process to provide comments on the Proposal for a Restriction of Per- and polyfluoroalkyl substances (PFAS) (hereinafter “Restriction Proposal”).

With this statement, we would like to explain why we believe that a derogation for aerospace and defence (hereinafter “A&D”) – which as such is not covered in its entirety by the derogations in the Restriction Proposal – is needed and justified. Further, we would like to explain why this derogation should be time unlimited.

The conclusions from our submission are summarised as follows:

- It would be beneficial and justified to capture all uses of PFAS within the A&D sector under one derogation.
- It is vital to consider future A&D requirements that cannot be achieved without PFAS (e.g., higher voltages, increased electrical current, faster data rates, and improved sealing which enable miniaturization, weight reduction, and fuel efficiency in conventional and increasingly electrified aircraft).
- Material property screening of potential alternative materials as well as direct experimentation to evaluate alternatives have demonstrated that no alternative is currently able to meet required performance that would allow replacement of fluoropolymers in sealants, cables, and capacitors for aerospace and defence applications.
- It is unlikely that feasible alternatives will be found in the foreseeable future and using alternatives that do not meet the performance requirements to the same degree as PFAS is not an option in the A&D sector due to system performance, reliability, and safety concerns.
- Gore believes that the A&D supply chain are united in seeing the benefits of the combination of properties delivered by fluoropolymers to certify and sustain the safety of interdependent and interconnected systems that cannot be replaced for existing aircraft and defence systems.

I. Derogation Request

Considering the arguments and evidence presented below, Gore respectfully requests to include the following sector-specific derogation for aerospace and defence in Column 2, paragraph 6 of the proposed restriction:

Aerospace and defence



II. Description of the End Use

1. Selected Aerospace and Defence Applications

Aerospace and defence applications are varied, complex and often have some of the most demanding standards for performance, operating conditions, and reliability in equipment and vehicles. Within the vast array of critical Aerospace and Defence applications, Gore manufactures products for selected end uses. We are providing information on those uses well-known to us: Sealants, Cables & Cable Assemblies, and Capacitors. End uses include, but are not limited to, application in satellites, space exploration vehicles, civil and military aircrafts. They are presented to aid understanding of possible applications of PFAS (in our case mostly fluoropolymers) within the A&D sector but are not intended to present an exhaustive list of possible products/ applications of PFAS within that sector.

a. Sealants

Sealants are used to seal airframes, panels, and other structures both in civil and military aircraft. Aerospace sealants have a significant impact on airframe functionality, operational performance, and maintainability. Airframes that aren't properly sealed and protected can become damaged over time from mechanical forces and harsh contaminants — ultimately leading to more maintenance. Tapes and gaskets increase aircraft surface life because they effectively protect aircraft panels from vibration, corrosion, aggressive fluids, and more. Equipment manufacturers specify dry, lightweight sealants because they simplify aircraft assembly, increase manufacturing throughput, improve safety, and reduce lifecycle costs.

b. Cables & Cable Assemblies

Cables provide a nervous system-like network of reliable signal transmission within aircrafts to control communications, safety, and mission critical systems, such as flight controls, radar, and aircraft survivability equipment. A single aircraft, satellite, or vehicle will have numerous cables and cable assemblies, each with unique performance requirements based on its specific use in a complex system.

c. Capacitors

Capacitors are critical components needed to stabilize power supply in an aircraft to drive both auxiliary system power and flight control systems. The trend towards electrification of aircraft is further increasing performance requirements and expected operating temperatures.

2. Product Examples

Detailed descriptions of the type of products and their reliance on PFAS is provided below. The product examples are all Gore products, as details of comparable products manufactured by other companies are not publicly available. We believe that these products are representative of products manufactured and placed on the EU market by

other companies but are not intended to present an exhaustive list of possible products/applications of PFAS within the A&D sector.

Based on the current proposal, only a few applications in Table 1 below might be provided with a derogation¹; however, these products all require a derogation to ensure continued reliability of critical vehicles and equipment in the A&D sector:

Table 1. Selected Aerospace and Defence Products

Product	Illustrations	Description
Gore® Skyflex® Aerospace Materials		Gaskets and sealants are used in aircraft structures to seal panels and protect surfaces mechanical forces and harsh environments that can severely damage aircraft structure. They protect against ingress or leak of fluids, minimise corrosion, reduce the impact of abrasion, and fill gaps. The materials make aircraft maintenance faster and simpler because they are lightweight, do not need to be cured, and are flexible to conform to any shape.
Gore® Aerospace Data and Power Cables		Cables used in aircraft systems to deliver high quality signals even in demanding conditions². Data cables Compact, flexible, and routable cables designed to significantly improve system performance in an aircraft³. Fibre optic and copper high speed data cables transmit MIL-STD-1553, ethernet, CANBus, FibreChannel, IEEE-1394b, MIL-STD-1760, discrete signals, and other protocols to operate critical flight control systems, passenger support system, and mission systems equipment in Civil and Defence Aircrafts. Data cables provide a nervous system-like network of reliable signal transmission needed to protect soldiers and aircraft with fully functional and finely tuned aircraft

¹ Some applications might fall under the paragraph 6o: “applications affecting the proper functioning related to the safety of transport vehicles, and affecting the safety of operators, passengers or goods until 13.5 years after EIF”. As this derogation is for reconsideration and it is unclear how safety is defined in this context, we suggest a derogation for aerospace and defence.

² Gore (2021) GORE® Aerospace High Speed Data Cables. Accessed: 28/09/2021. Available at: <https://www.gore.com/resources/aerospace-high-speed-data-cables-catalog>

³ Gore (2021) GORE® Aerospace High Speed Data Cables. Accessed: 28/09/2021. Available at: <https://www.gore.com/hdaircraftcables>

			survivability equipment and electronic countermeasures.
		Power cables	Used to power generators, operate flight controls, and support mission systems. Mission systems include radar and Aircraft Survivability Equipment such as Missile Warning Systems and Threat Jamming Equipment in Defence applications.
Gore® Microwave / RF Assemblies ⁴			Used to transmit and receive analog radio frequency (RF) signals to maintain communications, operate radar, test mission systems, and feed Aircraft Survivability Equipment such as Missile Warning Systems and Threat Jamming Equipment in Aircraft and other Defence equipment. This product category also includes Microwave Cable Assemblies. With respect to modern electronic warfare (EW), defence forces must be able to promptly and accurately detect enemies and take appropriate actions before enemies do. Advanced radar technologies rely on microwave cables to enable this early detection capability.
Gore® Space Cables and Assemblies.			Same properties as Aerospace Data and Power Cables and Microwave / RF Assemblies but designed to survive the harsh radiation, extreme temperatures, and vacuum of space.
GORE™ High Temperature Capacitors			Capacitors deliver stable voltage and capacitance at elevated temperatures. Key performance characteristics include reliable self-clearing, low dissipation factor, and thermo-mechanical stability. This enables significant design advantages in the Aerospace industry to improve power density in line with the Electrification megatrend to reduce global emissions.

⁴ This product is also used in the electronics and telecommunications industry.

All of the PFAS used in these products are fluoropolymers which meet the criteria for Polymers of Low Concern (PLCs), under the definition provided by the OECD Expert Group on Polymers. The PFAS used for each product are shown in Table 2.

Table 2. PFAS used in Aerospace and Defence Products

Product	Type of PFAS	CAS	Is this PFAS a PLC
GORE® SKYFLEX® Aerospace Materials	PTFE	9002-84-0	Yes
GORE® Aerospace Data and Power Cables	PTFE	9002-84-0	Yes
	FEP	25067-11-2	Yes
Gore® Microwave / RF Assemblies	PTFE	9002-84-0	Yes
	PFA	26655-00-5	Yes
	FEP	25067-11-2	Yes
	ETFE	25038-71-5	Yes
Gore® Space Cables and Assemblies	PTFE	9002-84-0	Yes
	ETFE	25038-71-5	Yes
GORE™ High Temperature Capacitors	PTFE	9002-84-0	Yes
	ETFE	25038-71-5	Yes

III. Reference in Restriction Proposal

1. Specific A&D needs are not addressed in the Restriction Proposal

A&D applications are not discussed as a separate sector/use within the Restriction Proposal. The A&D sector relies on a broad range of PFAS applications covering, among many others, electronic components (such as cables and wires or capacitors) and sealants.

Various applications, also relevant to A&D, are described under transportation (E.2.10.) and electronics sections (E.2.11.) but those sections give very limited considerations to the specific needs of A&D.

Gore welcomes that the important function fulfilled by fluoropolymers used in transport (including aerospace) is recognised by the Dossier Submitters. A derogation for

‘applications affecting the proper functioning related to the safety of transport vehicles, and affecting the safety of operators, passengers or goods until 13.5 years after EiF’ have been proposed for reconsideration (Restriction report, RO2, paragraph 60, page 8). We believe, however, that it is not sufficiently clear what type of specific applications would be covered, and whether it would cover military and space exploration applications at all.

For instance, the Restriction Proposal discusses mobile air conditioning (MAC) and refrigeration in military applications. It does not, however, recognize other essential applications of fluoropolymers such as sealants, wires and cables, or capacitors used in the defence sector on which we will elaborate in further sections of this document.

We welcome that the Dossier Submitters recognized the difference and more complex nature of military applications compared to civilian applications, namely the need to meet additional and more stringent performance criteria and the need to use equipment in hostile environments (Annex E, page 359-360). We believe the recognized difference also applies to other fluoropolymers applications within the defence sector, that has not been explicitly mentioned.

Also, it is recognized in the Restriction Proposal that aerospace standards require much longer approval-time and any new product introduction must consider separate quality management systems (*regulated under FIA and must confirm to ISOAS9100 and NADCAP systems*- see Annex E, page 354).

It would be beneficial and justified to capture all uses of PFAS within the A&D sector under one derogation. In the case of A&D, the need for a derogation is driven by the more complex and demanding performance and safety requirements of that sector.

2. Assessment of alternatives has not considered the specific performance requirements of A&D

Information on alternatives that may be relevant to PFAS applications within A&D are fragmented across transportation (E.2.10.) and electronics sections (E.2.11.).

Dossier Submitters recognized that in the area of electronics they ‘*received limited information on alternatives, however, does not fully understand whether these alternatives have the potential to be used broadly or can only be utilized in niche applications*’ (Annex E, page 401).

Dossier Submitters recognized that *any alternatives to fluorinated polymers for sealing applications in transportation vehicles need to meet various requirements. They need to have a durability against lubricants, fuels, diesel, cooling agents and/or other fluids and have to provide good sealing properties over wide range of temperatures* (Annex E, page 351).

The feasibility of an alternative in specific applications (whether it is a cable or sealant) is critically dependent on its sector of use. We welcome the fact that the Restriction Proposal elaborates about alternatives available for cables and wires and sealants, but we would like

to point out and demonstrate in the following sections that they are not suitable and would lead to severe risks when applied in the A&D sector.

The Restriction Proposal understandably focuses on current applications of PFAS and often assesses whether there are working alternatives on the market, or promising alternatives in the innovation pipeline, that could replace those current uses. The Restriction Proposal introduced three possible timeline options that apply without discrimination to every end use sector. Those timelines are:

- Ban 18 months after EiF
- Ban 6.5 years after EiF
- Ban 13.5 years after EiF

However, when it comes to sectors of strategic importance like A&D, taking away a possibility to innovate with such unique and beneficial materials as fluoropolymers, eventually could lead to impairing the EU A&D industry.

It is vital to consider future A&D requirements (e.g., high voltages to facilitate further miniaturization, increasing current generating heat, more electric aircraft) when assessing suitability of alternatives.

IV. Need and Justification for a Derogation

A time unlimited derogation for Aerospace and Defence is needed and justified. Without a derogation, risk to passengers, aerospace staff and military personnel will increase as a result of the use of materials that cannot provide sufficient performance. Gore does not exclude the possibility of finding a breakthrough material that could display the properties and performances needed for those applications; however, no material that could replace fluoropolymers is in sight. Additionally, putting a time-bound restriction on the use of fluoropolymers in the A&D sector, without considering both current and future needs of that sector, also risks endangering EU market competitiveness and security. We propose that a derogation is justified based on the following points:

- The **performance requirements** for Aerospace and Defence applications.
- 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 new A&D products.
- The **large socio-economic cost** of restricting the use.

1. Summary of Performance Requirements and Assessment of Alternatives

In September 2022, we provided a Use Assessment prepared by Eftec. The Use Assessment has been submitted to all 5 Dossier Submitters. Since this information was provided after the end of the Call for Evidence in September 2021, the Use Assessment is included as Attachment 3 listed in Annex II to this derogation request⁵.

To make the information more easily available and to consider the information provided in the Restriction Proposal, we have summarized information on alternatives in Annex I to this document which also contains updated and supplementary information obtained after the Use Assessment was submitted. The information on alternatives is provided at a product type level, referring to the products described in the Section II above.

Below, we summarize the conclusions from Annex I for the three product areas in focus for this derogation request: Sealants, Cables & Cable Assemblies, and Capacitors

a) Sealants

i) Summary of Performance Requirements

Performance requirements include both physical and chemical properties. Sealants must demonstrate:

- Mechanical properties include strength, density, width, flexibility at low temperatures, and stability under storage conditions to be able to maintain a reliable seal between equipment and vehicle parts subject to mechanical stresses and vibration.
- Thermal stability across an extremely broad range of temperature conditions. For example, aircraft are subject to high temperatures when parked in hot environments and quickly travel to extreme altitudes where temperatures are quite low. Materials need to remain stable at conditions outlined by an external standard (AMS3255).
- Chemical resistance due to exposure to common aircraft fluids
- UV resistance due to environmental exposure
- Passing flammability requirements from industry standards
- Ability to be installed safely and reliably

ii) Why Fluoropolymers are used in Sealants

Fluoropolymer-based sealants demonstrate exceptional chemical, temperature, and UV resistance while maintaining sufficient mechanical strength. All assessed alternatives lead to significant disadvantages when compared to expanded PTFE sealants. Researched and tested sealants alternatives have reduced durability and longer maintenance time/increased downtime which could cause reduced aircraft availability. The most

⁵ Since the UA has been created, we have also obtained additional information on use of fluoropolymers in capacitors.



common alternatives also lead to increased waste generation due to their shorter shelf life and non-reusability.

iii) Summary of Alternatives in Sealants

Polysulfide

Beside curing process difficulties⁶ in comparison to PTFE and additional installation time, polysulfide sealants are not chemically resistant to technical fluids used in commercial aircraft (like LD-4 Hydraulic Fluid). They will also add weight to aircraft, and they are classified as Volatile Organic Compounds. Some polysulfides are classified as carcinogenic Cat.2 and STOT RE Cat.2 as well as Acute and Chronic Aquatic Toxicity Cat.1.⁷

Nitrile Rubber

Sealants made of nitrile rubber show limitations due to aging, especially under UV exposure which makes this material brittle, easy to break, and reduces its reusability. More frequent failures and increased waste have caused downstream users to request the change to PTFE sealants.

Polyurethane (PU) gel tape

PU sealants are not dimensionally stable under a mechanical load, leading to less reliable seals, replacement, and substantial waste. They are also higher weight than PTFE materials, resulting in higher fuel consumption and CO₂ emissions.

Silicone foams

Silicone foam material can tear and crack easily (leading to premature product failure and increased waste) and is susceptible to degradation from contact with fuel and hydraulic fluids.

A visual comparison of alternatives is shown in Table 3 below:

⁶ Curing process susceptible to humidity and limited in time which makes it difficult to automate. Those points are explained further in Annex I

⁷ See SDS in attachment 5

Table 3. Comparison of Alternative Materials for Sealant Applications in A&D

PTFE Sealants	Polysulfide Wet Sealants	Polyurethane Tapes	Gel Tapes
✓ Provides surface protection (abrasion, corrosion, vibration, anti-chafe) ✓ Provide environmental sealing protection ✓ Repels aviation fluids like fuel, hydraulic (SKYDROL™), oil, de-icing ✓ Remains in place under compression with no squeeze out ✓ Non-curing with fewer process steps for easier and faster installation ✓ Maintains protective performance over multiple open/close cycles ✓ Requires no operator certifications, special equipment or PPE	△ Provides surface protection (abrasion, corrosion, vibration, anti-chafe) ✓ Provide environmental sealing protection ✓ Repels aviation fluids like fuel, hydraulic (SKYDROL™), oil, de-icing ✗ Remains in place under compression with no squeeze out ✗ Non-curing with fewer process steps for easier and faster installation △ Maintains protective performance over multiple open/close cycles ✗ Requires no operator certifications, special equipment or PPE	✓ Provides surface protection (abrasion, corrosion, vibration, anti-chafe) ✗ Provide environmental sealing protection △ Repels aviation fluids like fuel, hydraulic (SKYDROL™), oil, de-icing ✓ Remains in place under compression with no squeeze out ✓ Non-curing with fewer process steps for easier and faster installation ✓ Maintains protective performance over multiple open/close cycles ✓ Requires no operator certifications, special equipment or PPE	△ Provides surface protection (abrasion, corrosion, vibration, anti-chafe) ✓ Provide environmental sealing protection ✗ Repels aviation fluids like fuel, hydraulic (SKYDROL™), oil, de-icing ✗ Remains in place under compression with no squeeze out ✓ Non-curing with fewer process steps for easier and faster installation △ Maintains protective performance over multiple open/close cycles ✓ Requires no operator certifications, special equipment or PPE

b) Cables & Cable Assemblies

i) Summary of Performance Requirements

There is no single set of performance requirements for Cables and Cable Assemblies as a whole. Instead, the individual requirements vary by product type and in many cases are uniquely customized to the specific vehicle or system where the product will be used. These varied and demanding requirements require the availability of materials which can meet unique combinations of specifications. Cables and Cable Assemblies used in A&D applications must operate reliably over a long product life cycle that can reach beyond 30 years.



Key performance requirements include:

Dielectric constant (ϵ_r)

Dielectric constant is an important material characteristic which relates to the ability of the material to store electrical energy in an electrical field. Low dielectric constant values are necessary for high frequency or power applications to minimize electric power loss, enabling precise, consistent, and efficient signal transmission.

Service temperature range

Cables experience a wide range of operating temperatures from extreme conditions in varied climates, to low temperature at high elevation during flight and the extremes of space. As an example, cables must withstand the demanding A&D conditions above 150°C as highlighted in the Aerospace and Industrial Electrical Cable standard ANSI/NEMA WC27500 as published by NEMA (National Electrical Manufacturers Association). Some space applications can expose electrical components to temperatures well below -100°C.

Chemical resistance

The material must perform its function in harsh conditions and provide chemical resistance to oils, aircraft fluids, fuels, and other chemical substances.

Mechanical strength

The wires and cable materials must be highly durable and withstand frequent/rapid flexing, torsion, and pulling without compromising electrical performance under demanding environments (e.g., extreme temperatures).

Low coefficient of friction

The cable insulation and jacket layers must have a low coefficient of friction in order to decrease abrasion under continuous flexure and movement and during installation in aircraft and other systems.

ii) Why Fluoropolymers are used in Cables and Cable Assemblies

Fluoropolymers combine inherent electrical and mechanical properties with the unique ability to be processed into forms suitable for cable construction which are not available from other materials.

- Fluoropolymers like PTFE, FEP and PFA have a low dielectric constant of 2.1, where lower numbers enable higher precision and more reliable signal transmission.
- PTFE, in particular, can be processed into an expanded form which has an exceptionally low dielectric constant of 1.3.

Additionally, its maximum continuous service temperature (MCST) also enables:

- wide continuous use service temperature range, between -240 and +260°C

- good mechanical strength to withstand demanding mechanical and environmental challenges (i.e., withstanding handling, bending, torsion, and pulling without compromising electrical performance).

iii) Summary of Alternatives in Cables and Cable Assemblies

To operate in harsh and extreme conditions, cable applications need critical properties that only a small subset of potential materials can provide. Tables comparing materials' chemical stability, thermal stability and dielectric constant are provided in Annex I to exemplify the performance requirements. See Tables 5 and 6.

The materials discussed below may meet some of the performance requirements, but each has drawbacks or is unable to meet the necessary combination of requirements indicating they are not suitable for use in the A&D sector:

Polyimide

Besides its lack of flexibility, which complicates its use, this material displays a high dielectric constant, which limits its use in signal cables. It is also explicitly rejected as a material for applications where moisture is present, as humidity makes it even stiffer and increases the risk of breaks.

Polyesters, Polyethylene, Polyurethanes

Their max temperatures (80-125°C) mean they should not be used in aerospace applications as a significant drop in performance is typically observed over 80°C.

Moreover, they would require further additives for flame retardance⁸. In 1969, Notice 69-33 introduced in CFR (Code of Federal Regulations) Title 14 for Aeronautics and Space included a requirement to perform flame and burn tests to materials used in compartment interiors, cargo and baggage compartments, and electrical systems. This change has led to a replacement of less durable and worse performing materials with fluoropolymers. Therefore, any reversal to lower performing materials, such as those formerly used, is not an option as it would expose users (military, professionals and passengers) to increased, unacceptable risks.

Silicone

Although it allows for higher use temperature (180°C), silicones will be limited by their poor performance in signal/information cables due to their high dielectric constant.

Polyvinyl chloride (PVC)

PVC is the most popular jacket material for less demanding uses. However, in addition to its low resistance to abrasion and chemical substances, applications will be limited by its low Continuous Service Temperature (up to 80°C) and the outgassing property in thermal

⁸ Some flame retardants are classified as PBT and therefore will be subjected to regulatory measures of their own.

vacuum conditions⁹. This material is not a feasible alternative for high performance or custom end uses found in Aerospace and Defence applications.

Alternatives are not able to maintain dielectric and other material properties within the required temperature ranges to assure system performance within environmental conditions that can include radiation, presence of chemicals, and other factors. They also have insufficient flame retardancy as required by European and U.S. Wiring Standards EN3475 and SAE AS22759.

c) Capacitors

i) Summary Performance Requirements

Critical A&D systems require capacitors to meet the power needs of complex systems reliably and consistently. Capacitor reliability improves overall system reliability. Technology systems used in A&D applications (e.g., aircraft) must qualify to meet minimum lifetime targets. Lifetime targets are becoming more challenging because the continued electrification of aircraft systems lead to a trend of higher operating temperatures. Should a film capacitor fail in service, functionality of the entire system could be lost. For example, this could impact the operation of critical systems such as braking or aileron control system (safety concern) or require the pilot to reduce power consumption to avoid further system losses.

Key performance criteria include:

Ability to self-clear

Clearing is an ability to isolate a fault (dielectric breakdown) from the rest of the device. This allows the capacitor to avoid a catastrophic and complete failure even when there is a dielectric breakdown somewhere in the capacitor. It leads the capacitor to have increased reliability and prevent system failure.

Low Dissipation Factor

Dissipation factor is a measure of the power lost travelling through a capacitor, mainly as heat. When materials have a high dissipation factor, the ability to deliver sufficient power is compromised and can cause excessive heating leading to reduced lifetime and reliability.

High temperature operating range

Electrical system operation, as well as environmental conditions, can expose a capacitor to elevated temperatures. Capacitors need to withstand these temperatures, in some cases, in excess of 200°C without failure or a significant change in electrical performance.

⁹ Customers in aerospace sector have strict requirements on outgassing (especially under vacuum conditions)

ii) Why Fluoropolymers are used in Capacitors

Expanded PTFE technology uniquely combines reliable self-clearing, low dissipation factor, and thermo-mechanical stability. This improves reliability where capacitors are used today, and also enables further electrification of Aerospace systems which is a broader goal of the industry.

Capacitors are used in many applications that need to operate in a varied set of conditions. Therefore, there are a number of potential alternatives. The complete list of those potential alternatives is provided in Annex I where we also share their limitations and why those materials cannot be used in aerospace applications. In short, there are no known alternatives in the aerospace sectors that meet the power and reliability requirements, when considering the increasing power density and temperature conditions that the electrification of aircraft requires.

d) Alternatives Summary

As summarized above and shown in Annex I, **material property screening of potential alternative materials as well as direct experimentation to evaluate alternatives have demonstrated that no alternative is currently able to meet required performance that would allow replacement of fluoropolymers in sealants, cables and capacitors for aerospace and defence applications.**

2. Timeline

The A&D industry has been looking for alternative materials for cost saving opportunities for years without finding viable replacements for PFAS. Development, qualification, and transitions to alternative materials will require significant time and resources.

The Restriction Proposal only allows a transitional period of 13.5 years even in such cases where no alternatives are apparent. As pointed out on page 77 of the Restriction Dossier, this is based on the understanding of the Dossier Submitter that 13.5 years are *‘normally sufficient for industry to take benefit from technical progress and to carry out scientific R&D activities to find and deploy technically and economically feasible alternatives’*.

Based on Gore’s research and other available information, Section IV.1 confirms that no alternative materials are available at the time of writing and the combination of properties needed will be difficult to achieve in a new material (low dielectric constant, high service temperature, mechanical strength, chemical resistance, etc.). We will now underline the timeframe needed once a material with the suitable combination of properties has been discovered or invented for these applications.

Examples from the past, show that the time span to develop new materials can vary significantly. For example, the development of acrylic polymer took several decades. The process from the first synthesis of acrylic acid to the introduction of the commercial



polymer, was an 85-year journey.¹⁰ The development of PTFE from the “accidental” discovery to a commercial product took about 10 years, from 1938 to 1948,¹¹ and then decades more to mature that technology into the materials used today. Development advances over this time have had to occur in polymerization, finishing, lubrication and blending, pelletization, and extrusion to develop forms usable in end products. In the absence of such an initial unexpected discovery, we can only speculate that developing a new polymer to commercial availability will take more than 20 years.

Using the example of Cables and Cable Assemblies, after identifying a material, the possible alternative materials will need further development in order to optimise them for specific application requirements. We estimate that this development stage could take 2 to 3 more years. There is also no guarantee that the new material and the associated manufacturing of that material would be preferable from an environmental perspective, as it would replace what is intrinsically a safe polymer.

Furthermore, any potential non-PFAS alternatives will need to go through a lengthy qualification testing process that is required for A&D substances to be approved. As an example, Gore is involved in a new standard qualification process for wires and cables with Society of Automotive Engineers (SAE) International, that already has taken circa 5 years. In 1969, CFR (Code of Federal Regulations) Title 14 for Aeronautics and Space as overseen by the FAA and NASA within the United States were amended with Notice 69-33. The notice stated, “requirements need to be considered in the initial design stages of an airplane, which is several years prior to the issuance of the type certificate, and to impose them on airplanes nearing type certification might require a substantial redesign of the airplane and would necessitate production-line type design changes” (page 23). Forty-four years later, the time to redesign and recertify aircraft will be impacted even more due to the additional complexity of interdependent systems that rely on fluoropolymer performance.

The final optimised material will then need to be manufactured into cable assemblies that can be evaluated and qualified both at a manufacturing and end-use level. Integration and qualification of cables into complex A&D systems is a complex and time-consuming activity. It can be even more challenging to qualify new materials as replacement parts in systems which are currently operational and may have a life of 20 or more years remaining.

¹⁰ See <https://www.ptonline.com/articles/tracing-the-history-of-polymeric-materials-part-20>.

¹¹ [https://www.teflon.com/en/news-events/history#:~:text=An%20Accidental%20Discovery&text=Roy%20J.,to%20form%20polytetrafluoroethylene%20\(PTFE\)](https://www.teflon.com/en/news-events/history#:~:text=An%20Accidental%20Discovery&text=Roy%20J.,to%20form%20polytetrafluoroethylene%20(PTFE)).

Table 4. Substitution Steps for Developing an Alternative to Fluoromaterials in Aerospace & Defence Applications

Steps for substitution	What activities does this step entail?	Time required for step
1. Identification and development of new material	Identify and develop suitable alternative materials. Product Development from lab discovery to pilot scale.	Unknown Estimate > 20 years
2. Product development an iterative stage of R&D, (re)formulation and lab testing	Optimise material for specific application requirements	2-3 years
3. Qualification and/or Validation - testing and validation with customers and/or external testers	Reliability testing of manufactured components.	2-5 years
4. Production - implementing the manufacturing plan for the alternative, including a possible pilot phase, regulatory approval, and modifications to the production line.	Supply chain development (new production capabilities and capacity for mass production).	2-5 years
5. Integration and qualification into end system or vehicle – Development and testing of product in-use with end device	Development cycle of new end device	3-7 years
Total		Unknown Estimated >29 years

3. Additional Information

a. Use Assessment

Additional Information can be found in the Use Assessment for A&D – Attachment 3, listed in Annex II to this derogation request. Among others, the following information is available in the Use Assessment:

- Market information
- PFAS use volumes

b. Social, Environmental and Economic Impacts

Components made using PFAS are necessary in the A&D sector to:

- Enable continued advances in the capability and reliability of aircraft, vehicles, and a range of electronic systems used in A&D applications

- Ensure the safety of passengers and the crew (or soldiers and space crew in space and defence industries)
- Reduce design and manufacturing costs for aircraft and vehicles
- Reduce operating costs due to increased reliability of components and reduced unplanned maintenance
- Lower the emissions from air travel by using lighter weight components
- Meet the regulatory requirements and industry standards.

Impact on Performance and Innovation of Critical Defence and Aviation Systems

For technically demanding uses with strict performance requirements, we believe a more in-depth and careful assessment of alternatives is needed. This is even more important for uses affecting people's safety and security, such as A&D, as the risk of failure is of much higher consequences. The risk related to reduction and withdrawal of A&D systems at various stages of development involving fluoropolymers, which would inevitably happen if a derogation is limited to 13.5 years, would jeopardize advancements in improved and more reliable defence systems as well as technologies that enable aircraft emissions reduction.

Risk of Component Failure leads to Increased Costs and Safety Risks

One of the key benefits of using PFAS in A&D products is increased performance due to their reliability, durability, and signal integrity. If PFAS can no longer be used, end products will be more impacted by electrical, mechanical, and environmental stress, making them more prone to wear and tear or damage. As a result, end-users will need to replace both the A&D products and end products (e.g., aircrafts) more frequently until a suitable alternative to PFAS in A&D products has been found. When aircraft or other equipment needs more frequent unplanned maintenance, it is not available for operational tasks which can have serious implications for aviation or defence capabilities. Product redesign and changes in downstream users' production processes will disrupt ongoing development efforts, which means that there is a risk of temporary production halt for products relying on PFAS-containing A&D products.

Availability of Spare Parts

It is also vital to ensure that spare parts made with PFAS are available for maintenance of both civil and military aircrafts and other vehicles/equipment as in the sector of A&D they have a service/shelf life of decades (40 years +). If restriction does not exempt A&D or forces producers to cease production, spare parts of the same specification will not be available. Alternative materials, if even developed, may not allow for a direct replacement within complex technologies of A&D resulting in premature obsolescence of parts or products. This would have huge economic, strategic (due to unavailability of functioning military equipment), and environmental (due to unnecessary waste and resource consumption) impact.

Annex I – Alternative Assessment

We would like to note that W. L. Gore & Associates has limited knowledge regarding hazards and risks presented by materials we do not manufacture or use. Information on hazards and risks of alternative chemicals presented below is based solely on desk research. All those chemicals are subject to REACH regulation and any applicable national workplace laws. Therefore, the information below is not to be seen as a judgement on the suitability of their use. We believe that before a restriction on the use of fluoropolymers, which are non-hazardous and non-bioavailable is implemented, a comprehensive comparative risk assessment throughout the entire lifecycle should be conducted on any potential alternatives.

Sealants

Performance requirements	- Tolerance to extreme temperature swings (Example: -73°C to 260°C per AMS3255B Class 1-4) - Chemical resistance and ability to seal against fuel, environmental fluids, and hydraulic fluids - Simple aircraft assembly and maintenance which leads to reduced cycle times and increased aircraft availability - Reusability and waste reduction compared to alternatives - Surface protection and high conformability - Qualified to customer specifications and industry standards - Mechanical strength, dimensional stability, and durability
Alternative materials assessment	Polysulfide Sealants <u>Polysulfide does not have sufficient chemical resistance.</u> It does not resist LD-4 (aircraft fluid), and is less resistant to water compared to PTFE-based products, leading to quicker failure over time resulting in more frequent maintenance <u>Polysulfide needs to be cured.</u> Polysulfide is applied as a liquid and the curing process is negatively impacted by temperature and humidity conditions. Once a pot of polysulfide is mixed, there is a specific time in which it must be used. Additionally, maintenance engineers may not need an entire pot but have to mix the entire pot. Both limitations generate additional waste. Also, viscosity between batches of liquid sealants can vary. These factors may prohibit use of automation in the manufacturing processes. <u>Polysulfide is not suitable for every application</u> where PTFE sealants are used. For example, it is not a suitable alternative in floorboard applications of the aircraft. Polysulfide is too tacky for use under floorboards – it becomes difficult to re-open the panel and any excess of the wet sealant (referred to as the “squeeze out”) can lead to production and cleaning problems when it gets onto unintended areas of the aircraft. <u>Polysulfide use requires additional workplace controls.</u> The solvent in polysulfide is a Volatile Organic Compound (VOC) and requires maintainers to work in a hood with

	proper air circulation. There is a high amount of effort needed to clean up sealed areas which entails the use of teams of operators who use large quantities of VOCs to remove excess or poorly placed cured sealant. This generates high VOC emissions. Polysulfide sealants are hazardous mixtures. US OSHA hazard classification: Acute Tox Cat 4 (oral and inhalation), Cancerogenic Cat 2, STOT RE Cat 2 EU SDS was not available. Polysulfide has a significantly longer installation and maintenance time. PTFE-based sealants enable surface protection and corrosion reduction can positively impact WIP times at bottlenecks. In a real case study¹² when various panels need to be reopened for maintenance multiple times, ePTFE sealants have shown great superiority to Polysulfide wet sealants, leading to a reduction of installation time from 50 to 4 hours. For detailed information including time analysis graphics please refer to: - Attachment 1 - IMPROVING AIRCRAFT AVAILABILITY WITH ALTERNATIVE SEALANTS (Note that in the second graphic, MIL-S-8802 is synonymous with polysulfide) - GORE-SKYFLEX-Materials-Leonardo-Case-Study¹² <u>Large amounts of disposal and transportation of waste:</u> Polysulfide sealants are single-use and cannot be reused. Short shelf life also means that any excess mixture must be disposed of as hazardous waste. For all precautionary and risk management measures see SDS- Attachment 5 <u>Nitrile Rubber</u> <u>Nitrile rubber may move in application, causing a risk to the aircraft and safety of the crew/passengers.</u> It is not as conformable as PTFE sealants, so it might move within application and not seal if not properly installed. <u>Nitrile rubber is not sufficiently UV resistant.</u> Under UV exposure, it will break down and become brittle risking seal failure. <u>Nitrile rubber is more complicated to handle for customers.</u> Nitrile rubber is not reusable compared to PTFE gaskets so there is more waste generated. Nitrile rubber also has a higher weight than PTFE leading to higher weight of aircraft. Airbus had previously requested to change from nitrile rubber to PTFE-based sealants due to complicated handling work and deformations that has appeared when using nitrile rubber- Attachment 2
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¹² https://www.gore.com/system/files/2020-07/GORE-SKYFLEX-Materials-Leonardo-Case-Study-M-345%20Trainer-05262020_0.pdf

	<u>Polyurethane (PU) Gel Tape</u> <u>PU gels create additional waste:</u> Gore is aware of companies using a PTFE scrim or PTFE release layer with PU Gel tape. This approach still relies on fluoropolymers and can squeeze out in the application a failed seal, safety risks and premature replacement. They are not recoverable or reusable, leading to waste. <u>PU lead to other installation and aircraft performance challenges.</u> Gels take more time to replace in application compared to 100% PTFE sealants. Additionally, they are higher weight than expanded PTFE leading to higher weight of aircraft. <u>Silicone Foams</u> <u>Safety and waste:</u> Silicone sealants can tear and crack easily leading to sealing deficiencies and premature replacement. If the seal fails and fluids leak into areas of the aircraft, this could cause mechanical damage to the airplane and take of aircraft out of service more frequently. <u>Silicone foams are specific to floorboard applications.</u> They cannot be used in all applications where PTFE sealants can be used due to their low tensile strength. They are not able to withstand vibrations and high compression in other areas of the aircraft. <u>Silicone foams hold moisture</u> and do not resist fuel or hydraulic fluids like PTFE sealants. They have retained moisture and trapped dirt in application. Only PTFE sealants are able to meet the combination of mechanical and chemical properties required for sealants in A&D applications. See further information in the sections below and in Attachment 4 – Sealant Technologies in Commercial Aircraft
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Cables and Cable Assemblies

Performance requirements	Cables used in A&D applications are often custom designed to unique performance requirements for a specific type of vehicle, aircraft or satellite system which may differ from a similar system in the same end use. The user of these cables specifies the electrical signal performance and the physical conditions it must withstand. These physical demands can include attributes such as torque/crush/kink resistance, abrasion resistance, dust/moisture resistance, performance over a wide temperature range, chemical resistance, high flex, and high connector pull strength. Cables achieve these performance attributes though a combination of the inherent properties of the materials used, plus the design and construction techniques used
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by the manufacturer. Cables have overall electrical performance requirements such as:

- ultra-low attenuation of microwave/RF and high-speed differential signals over distance to provide adequate signal transmission with physical, environmental, and electrical challenges of A&D end uses
- smaller phase/amplitude change over temperature to provide adequate signal transmission with physical, environmental, and electrical challenges of A&D end uses
- shorter time delay of microwave/RF signal over distance to provide adequate signal transmission with physical, environmental, and electrical challenges of A&D end uses
- lower capacitance over distance to enhance precise and accurate microwave/RF signal transmission

Both electrical and physical performance of the cables are influenced by the inherent properties of the materials used. Key material properties include:

- Low dielectric constant values are necessary for high frequency or power applications to minimize electric power loss, enabling precise, consistent, and efficient signal transmission
- Wide continuous use service temperature range (i.e., -240 to +260°C, typical) to provide adequate signal transmission with physical, environmental, and electrical challenges
- Low outgassing in thermal-vacuum conditions to provide adequate signal transmission with physical, environmental, and electrical challenges of A&D end uses
- Adequate mechanical strength to withstand demanding mechanical and environmental challenges
- Resistance to abrasion
- Resistance to water/oil/chemical substances
- Radiation resistance

See characteristics listed in section titled: “Alternative materials known or discussed in Restriction Proposal and performance of such materials” for specific performance ranges.

For example: A microwave/RF cable assembly, made with fluoropolymers, has overall operating temperature derated to -160 to +200°C to account for self-generated heating from microwave signal(s) being transmitted in the worst-case scenario (e.g., highest operating temperature @ +200°C with highest possible microwave power being transmitted). If a microwave/RF test cable assembly is made with non-PFAS materials, its overall operating temperature will have to be derated further (e.g., -25 to +85°C). **This reduced temperature range is not sufficient to accommodate the temperature range for civil and military aircrafts, and spaceflight vehicles.**

Alternative materials known or discussed in Restriction Proposal and performance of such materials

Cables and Cable Assemblies in A&D applications require materials to meet combinations of performance requirements simultaneously which eliminates many materials from being feasible. Table 5 below summarizes the performance of various materials against A&D requirements.

Table 5. Comparison of Performance Characteristics

Comparison of Performance Characteristics of Various Materials for Typical Aerospace Requirements

Known performance characteristics are approximate.

Characteristic	Typical Aerospace Requirements	Materials							
		Fluoropolymers	Polyimide	Polyester	Polyethylene	Polyurethane	Silicones	PVC	Foamed Polyethylene
Max Temperature ^(1,2)	200 C								
Min Temperature	-65 C; Cold Bend EN3475-406								
Flammability, Toxicity	EN3475-407, EN3475-602								
Chemical Resistance ⁽³⁾	EN3475-411								
Arc Tracking	MIL-STD-2223				?	?	?		?
Hydrolytic Stability	EN3475-412								
Long-term Thermal Stability ⁽¹⁾	EN3475-416								
Dielectric Constant ⁽⁴⁾	Low Er for Smaller, Lighter Weight Cables								
Cut-through Resistance /Abrasion Resistance	EN3475-503/EN3475-501								
Flexibility (Stiffness and Springback Force)	AS4373-707 (Gore experience)								
S P A C E	Low Loss Over Broad Temperature Range ⁽⁵⁾								
	Outgassing								
	Radiation Resistance	Cross-linked ETFE performance unique							

Legend: Meets Requirement Marginal Performance Does Not Meet Unknown

Sources of Information

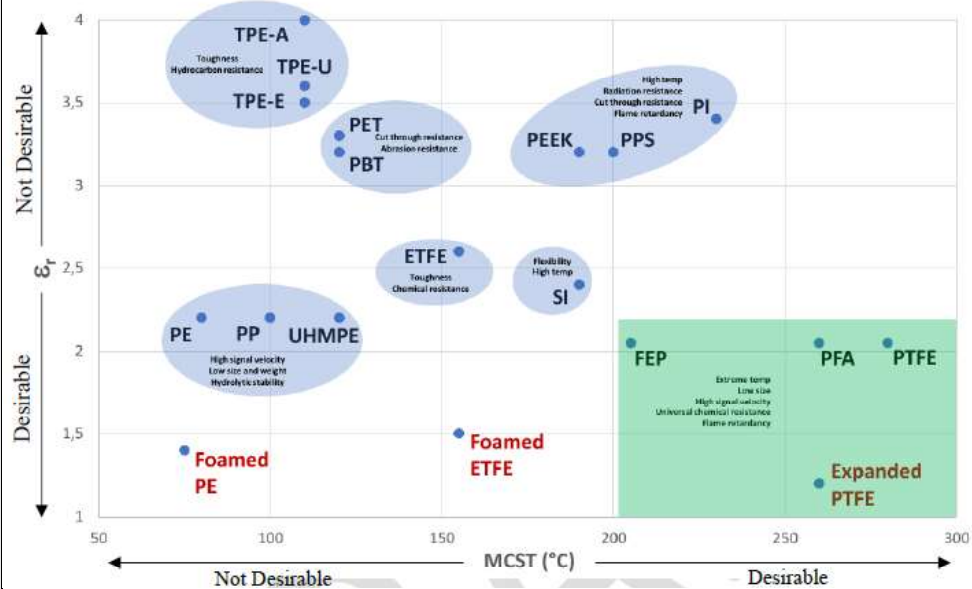
- (1) - "Max Temperature - Thermal Index. The thermal index is computed using the projected 15,000 hour life based on the ASTM D3032, Section 14. The minimum thermal index shall be 200 C" (Ron Solomon, June 1991, *New Insulation Constructions for Aerospace Wiring Applications* (WL-TR-91-4066 Volume 1). St. Louis, Missouri.; McDonnell Douglas Corporation. p. 15). (Lectromec 2016)
- (2) Use of Cables on Aircraft - Lectromec (Link: <https://lectromec.com/use-of-cables-on-aircraft-part-1/>)
- (3) Rating for Chemical Resistance taken from Chemical Resistance Chart PN 41-6018/rev. C (Emerson Process Management, 2010; Link: <https://studylib.net/doc/18540781/chemical-resistance-chart---emerson-process-management>; <https://studylib.net/doc/18540781/chemical-resistance-chart---emerson-process-management>)
- (4) Dielectric constant: for microwave cable assemblies' dielectric material, smaller dielectric constant values are more desirable because it concurrently enables ultra-low attenuation of microwave/RF signal over distance, smaller phase/amplitude change over temperature, shorter time delay of microwave/RF signal over distance, and lower capacitance over distance to enable precise and accurate microwave/RF transmission
- (5) The sustainable use of PTFE in Wire and Cable, Gore Internal White Paper, Amadeus Wieseemann, November 2022.

Dielectric Constant and Temperature

Having a sufficiently low dielectric constant eliminates most alternatives from consideration as alternatives in A&D Cable applications. Additional requirements such as temperature and chemical resistance eliminate the remaining non-fluoropolymer alternatives. This point is further highlighted in Figure 1 below, which demonstrates that fluoropolymers have the required combination of dielectric

constant rating and maximum continued service temperature (MCST) for A&D applications to provide adequate signal transmission with physical, environmental, and electrical challenges.

Fig. 1: Dielectric Constant (ϵ_r) vs. Maximum Continuous Service Temperature (MCST)



Chemical Resistance

Table 6 below shows chemical resistance of a range of polymers to the broad list of fluids, fuels, and cleaning solvents that are commonly used in the Aerospace industry as defined by Table 17 of SAE AS 22759, which is a broadly used Cable standard. Only fluoropolymers are sufficiently resistant to a broad range of chemicals, including hydrocarbons which are particularly relevant to A&D applications.

Table 6. Chemical Resistance of Polymers¹³

Note: PTFE is referred to as TFE

	ETFE	FEP/TFE/PFA	FLPE	FLPP	HDPE	LDPE	PC	PETG	PP	PVC	TPE***
Acids, Dilute or Weak	E	E	E	E	E	E	E	G	E	E	G
Acids, **Strong/Concentrated	E	E	G	G	G	G	G	N	G	G	F
Alcohols, Aliphatic	E	E	E	E	E	E	G	G	E	G	E
Aldehydes	E	E	G	G	G	G	G	G	G	G	G
Bases/Alkali	E	E	F	E	E	E	N	N	E	E	F
Esters	G	E	G	G	G	G	N	G	G	N	N
Hydrocarbons, Aliphatic	E	E	E	G	G	F	G	G	G	G	E
Hydrocarbons, Aromatic	G	E	E	N	N	N	N	N	N	N	N
Hydrocarbons, Halogenated	G	E	G	F	N	N	N	N	N	N	F
Ketones, Aromatic	G	E	G	G	N	N	N	N	N	F	N
Oxidizing Agents, Strong	E	E	F	F	F	F	F	F	F	G	N

*Not for tubing chemical resistance (except PVC) **Except for oxidizing acids (See oxidizing agents, strong) ***TPE gaskets

EXCELLENT	GOOD	FAIR	NOT RECOMMENDED
30 days of constant exposure causes no damage. Plastic may tolerate for 30 years.	Little or no damage after 30 days of constant exposure to the reagent.	Some effect after 7 days of constant exposure to the reagent. The effect may be crazing, cracking, loss of strength or discoloration.	Immediate damage may occur. Depending on the plastic, the effect may be severe crazing, cracking, loss of strength or discoloration, deformation, dissolution or permeation loss.

Additional notes on each alternative material:

- **Polyimide**
 - Prone to arc tracking after exposure to water (humidity)
 - High dielectric and stiff nature of the material makes polyimide not feasible for signal cables
 - Aircraft Wiring Degradation Study performed by Raytheon Technical Services Company LLC on behalf of Federal Aviation Administration, U.S. Department of Transportation concluded that “*Aircraft wiring systems should be designed to minimize the risk of wires being subjected to a tighter than 10-times dynamic bend. The use of PI (Polyimide) or PV wire in high moisture level areas is not a recommended safe practice because of the significant role that moisture plays in the aging of those wire types.*” (Raytheon Technical Services Company LLC , 2008, p. 92)
- **Polyesters**
 - Max temperature of 125°C makes polyesters a poor choice in Aerospace applications
 - Cut through performance¹⁴ is significantly lowered above 80°C

	○ Additives needed for flame retardance (additives may be substances of concerns themselves – like bromides) (Afirm Group, 2018) ○ Not resistant to typical fluids and chemicals seen in Aerospace Applications • Polyethylene ○ Max temperature of 80-120°C makes polyesters a poor choice in Aerospace and Defence applications ○ Cut through performance is poor ○ Additives needed for flame retardance (additives are substances of concerns themselves – like bromides) (Afirm Group, 2018) • Polyurethanes ○ Max temperature of 120°C makes polyurethanes a poor choice in Aerospace applications ○ Cut through performance is poor at all temperatures ○ Additives needed for flame retardance (additives are substances of concerns themselves – like bromides) (Afirm Group, 2018) • Silicones ○ Temperature range up to 180°C ○ Cut through resistance is poor ○ High dielectric constant and poor loss tangent of silicones means they are not feasible for signal cables • Polyvinyl chloride (PVC) ○ Not a viable alternative, does not meet any of the performance criteria ○ Similarly as in case of Polyamide Aircraft Wiring Degradation Study concluded that the use of PV wire in high moisture level areas is not a recommended safe practice (PV is defined as Polyvinyl Chloride/nylon) (Raytheon Technical Services Company LLC , 2008) ○ Additionally, ANSI/NEMA WC 27500-2020 (American National Standard for Aerospace and Industrial Electrical Cable Section 3.8.2.5 concludes that “Polyvinyl chloride shall not be used for aerospace purposes.” (Standard available from National Electrical Manufacturers Association, under copyright) • Foamed Polyethylene ○ Max temperature of 8 -120°C makes polyesters a poor choice in Aerospace applications ○ Cut through performance is poor ○ Additives needed for flame retardance (additives are substances of concerns themselves – like bromides and halogens) (Afirm Group, 2018)
R&D activities conducted	Gore has tested polyimide insulated aircraft wiring in a commonly used Teflon®/Kapton®/Teflon® variant. Gore’s R&D showed that the Kapton® layer can

¹³ Eason, M., & Vogel, R. (2022, May). Sealing Devices and the need for PFAS. Valve World, 20-22.

¹⁴ A wire/cable’s ability to withstand compression damage, which is one of the most common means for damage to a wire/cable on an aircraft

	be exposed through moderate abrasion whereby the Kapton is susceptible for corona discharge to occur leading to arc tracking and ultimately fire.
Conclusion	Only fluoropolymers are able to meet the combination of electrical, mechanical, thermal, and chemical properties required for Cable and Cable Assemblies in A&D Applications.

Capacitors

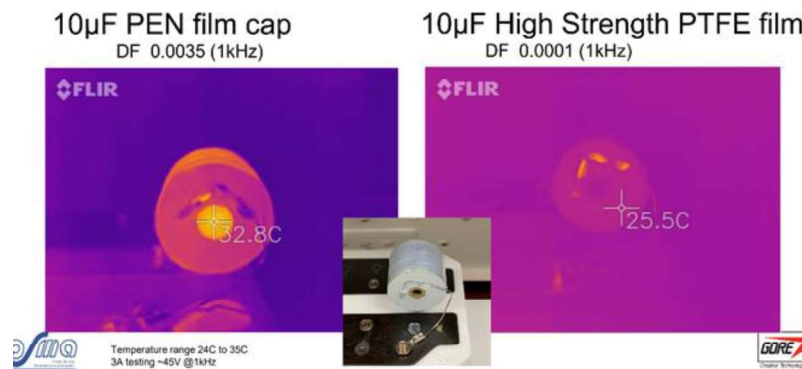
Performance requirements	Traditionally, the use of secondary power within civil aircraft has fallen into three general categories, Hydraulic, Pneumatic, and Electrical power. Current trends are seeing manufacturers move towards replacing traditional secondary hydraulic and pneumatic power systems with electrical alternatives. Electrical aircraft could achieve lower fuel consumption and emissions. However, before full electrification is feasible there are still numerous reliability issues to be resolved; especially within power electronics. The primary stressors affecting the reliability of several components within power electronics systems, such as printed circuit boards (PCBs), semiconductors, and capacitors are temperature-related (Wileman, Aslam, & Perinpanayagam, 2021). It is therefore necessary for capacitors in the aerospace sector to meet the following improved performance characteristics: - Low Dissipation Factor – a materials ability to self-heal when under charge and resist sudden catastrophic failure¹⁵ of a capacitor. A high dissipation factor indicates high energy loss and lower lifetime reliability. - High breakdown strength over temperature - High Insulation Resistance over broad temperature range - Low dielectric loss over temperature - Low dielectric loss over wide frequency range - Stable capacitance over wide range of temperatures and voltages An analysis focused on dissipation factor and temperature resistance is sufficient to demonstrate the lack of alternatives to fluoropolymers. See presentation: High temperature Capacitor Applications in More Electric Aircraft presented at Applied Power Electronics Conference 2018 (W.L. Gore & Associates, 2018)
Alternative materials known or discussed in Restriction Proposal and performance	<u>Alternative Material Technologies – Ceramics and Metallized Film</u> A variety of high temperature capacitor dielectrics exist such as ceramics (MLCCs) and Electrolytics, however, these suffer catastrophic failure risk from fracture or loss of electrolyte respectively. Metallized film capacitors exhibit a self-clearing phenomenon whereby excursions of electrical stress can be accommodated without catastrophic failure, making this type

¹⁵ Catastrophic failure is defined as a total loss of capacitance. Catastrophic failure implies collateral damage to the rest of the system resulting in down time and unscheduled field service

Page 28

Figure 3 (below) shows an exemplary visual comparison of dissipation factor and self-heating between PEN and PTFE film. The lighter colour seen in the PEN film cap indicates it is operating at a higher temperature due to its high dissipation factor. Generally, a 10°C increase in operating temperature will reduce component lifetime by about 50%. Thus, the hotter cap will degrade faster and be more likely to fail during use.

Figure 3. Comparison of Operating Temperatures of PEN and PTFE films



In Table 7, we present some key disadvantages of various materials when used in extremely harsh environments such as A&D, including a column which describes its current application. We also included materials applied in Oil & Gas Downhole tools, to present their deficiencies, in case they were considered for A&D applications.

Table 7. Performance Challenges with Alternate Materials in A&D Capacitors

Non-Fluorinated Alternative Material	Material Type	Application	Disadvantages
Class 2 Ceramics (X7R)	Ceramics	Power conditioning in downhole tools	Fail catastrophically; susceptible to fracture from shock & vibration
Class 1 Ceramics (COG)	Ceramics	Sensors, resonant circuits	Temperature stable but very low capacitance density due to the lack of BaTiO ₂ loading
Wet Tantalum	Hermetically sealed tantalum with electrolyte	Power conditioning in downhole tools	Fail catastrophically; susceptible to overvoltage/reverse current surges. Typically low max voltage ~125V.
Polypropylene (Treofan)	film (PP)	Aircraft power conditioning when combined with cooling systems	Limited to ~105°C. Available since the 1950's. Dominant film capacitor dielectric. Dissipation factor 2x PTFE. The added weight of cooling systems required to utilize PP film will disallow the Aircraft industry

from meeting global emissions goals.			
Polyimide (Kapton)	film (PI)	Space power electronics	Typically thick film/foil format; poor clearing; Dissipation factor 20X PTFE. Poor DWV leading to large form factor (poor energy density)
Polyethylene Terephthalate (Mylar)	film (PET)	Widely used but not often in aircraft power systems	125°C max temp. Widely used but not in high current applications. Dissipation factor 50X PTFE.
Polyphenylene Sulfide (Torelina)	film (PPS)	Marketed as HT film dielectric but sees little use above 125C	Largely replaced polycarbonate in the 1980's. Limited to 125°C. Poor clearing. Dissipation factor 180X PTFE. (self-heats significantly)
Polyethylene naphthalate (Teonex)	film (PEN)	Marketed as HT film dielectric but sees little use above 125C	Introduced ~2012 as HT capacitor film but limited to 125°C. Dissipation factor 35X PTFE.
Polyetherimide (Ultem)	film (PEI)	Marketed as HT film dielectric but sees little use above 125C	Marketed for use at 150°C but little adoption above 125°C. Dissipation factor 22X PTFE.
Polycarbonate	film (PC)	Precision capacitors, RC circuits	125°C max temp. Widely used but not in high current applications. Dissipation factor 50X PTFE.
Polycharge	Polymer deposition	Traction inverters	Mostly focused on automotive market, but capability is up to 140°C. Dissipation factor 25X PTFE. Not generally available.
Electrolytic (CDE high temp)	Aluminum electrolytic	Power conditioning in downhole tools	Fail catastrophically due to the evaporation of electrolyte, which leads to increased ESR, thermal runaway & shorting. Struggles to survive at high temperatures. Has a low max voltage (~300V).
<u>Additional References:</u> For an overview of film dielectric materials, see publication (Foster, James C General Electric Company, 1990) See presentation: High temperature Capacitor Applications in More Electric Aircraft presented at Applied Power Electronics Conference 2018 (W.L. Gore & Associates, 2018) to see the detailed comparative analysis of performance of alternative materials Also see a publication in Elsevier that provides an overview of the significant technical challenges required to meet the proposed 80% reduction in CO₂ emissions by 2050 (Clean Sky2). This paper cites industry surveys which specifically call for necessary			

	development into capacitors for harsh environments (high temperature) required to meet these goals.
R&D activities conducted	Gore has tested PTFE, PPS (polyphenylenesulfide), PEN (polyethylene naphthalate), and PEI (polyetherimide) films for dielectric lifetime based on an analysis of reliable self-clearing. Each of these film dielectrics are marketed as suitable in the 125–150°C range and were regarded the latest advancements in higher temperature film dielectrics. PTFE film substantially outperformed the other options at 150°C, by achieving 3 times higher lifetime. PEN and PPS films demonstrated catastrophic failure above 125°C and PEI demonstrated catastrophic failure above 150°C. PTFE film demonstrated reliable clearing as high as 225°C. Clearing is an ability to isolate the fault (dielectric breakdown) from the rest of the device. Note: In the above study, the older high temperature capable films introduced in the 1950's were not included such as PI (polyimide), PC (polycarbonate), and PET (polyethylene terephthalate) due to the well-established, market-recognized drawbacks of poor clearing (PI), high self-heating (PET), and general un-availability (PC). In another study performed in 2018, PTFE film was tested in a capacitor form to demonstrate the impact of a low loss dielectric (low dissipation factor). PEN (polyethylene naphthalate) material was used for comparison, as this was the latest/emerging high temperature film dielectric marketed at the time. PTFE film achieves up to 3.5 times greater current handling capability because of the lower power loss characteristics of the film. (See poster summarizing the results- attachment 6)
Conclusion	Material property screening and experimental results confirm that PTFE film uniquely combines reliable self-clearing, low dissipation factor, and thermo-mechanical stability that is required for Capacitors in A&D applications. Alternative materials are unable to meet the performance requirements.



Annex II - Overview of attachments supporting the request

<u>Reference</u>	<u>Document Title</u>
Attachment 1	- IMPROVING AIRCRAFT AVAILABILITY WITH ALTERNATIVE SEALANTS
Attachment 2	- Replacement of Nitrile Rubber inquiry
Attachment 3	- Final Use Assessment A&D
Attachment 4	- Sealant Technologies in Commercial Aircraft
Attachment 5	- SDS for Polysulfide Part A and Part B (two PDF documents)
Attachment 6	- PEN vs Gore Capacitors_ECTMApril2018



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