EUROMOT

Brussels, Belgium

The impact of a Potential PFAS Restriction on Internal Combustion Engine and Alternative Powertrain Manufacturers

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Note on report approval

The persons identified above have signed off each stage of this report in accordance with RINA's BMS/QA procedure.

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FEEDBACK QUESTIONNAIRE

As a valued client your feedback on this project is important to us. We would be grateful if you could spare a few minutes to complete the questionnaire found via the QR code or hyperlink below:

Link: RINA Questionnaire

Thank you.

Issue and Revision Record

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EXECUTIVE SUMMARY

RINA Tech UK Limited (RINA) was requested by European Association of Internal Combustion Engine and Alternative Powertrain Manufacturers (EUROMOT) to gather information from members to support the stakeholder engagement currently being undertaken for Per- and Polyfluoroalkyl substances (PFAS) under the REACH restriction proposal. Based on this information, this report provides an assimilation of the technical requirements which apply to EUROMOT members' products regarding uses of PFAS.

EUROMOT has represented the key global manufacturers for over 30 years. EUROMOT comprises 37 members and provides a hub of expertise for businesses, authorities, regulators, and public stakeholders worldwide, partnering with major sector associations and institutions for sustainable innovation. The technologies enabled by EUROMOT products cover a wide array of fields including construction, mining, marine, agriculture and power distribution to name a few, and have a fundamental role in the development of infrastructures and the continuous operation of high reliability applications such as auxiliary power generators for hospitals and firefighting stations.

EUROMOT members are end product users of PFAS substances and therefore rely on their suppliers to develop and provide PFAS-free alternatives. Alternatives investigated to date are not suitable for EUROMOT applications which are characterised by demanding environments with high contamination from dust and pollution, high temperatures and vibrations and presence of harsh chemicals. In these conditions, PFAS polymers are the only know materials with the technical characteristics to withstand those environmental conditions and guarantee reliability over the lifetime of the devices. In particular PFAS offer the following properties:

- Resistance to cycles of high and low temperature (-70 to 280°C), in presence of high vibration environments and harsh chemicals (pH as low as 1), for a prolonged period of time while ensuring the reliability of the device,
- Resistance to ozone-induced cracking after exposure and stability of the geometry and the plasticity of the components even after prolonged unuse,
- Chemical resistance to contact with fuel and lubricant oil without swelling above the allowed extent,
- Low friction characteristics in dry lubricant uses where tight geometries are used or cross contamination with fuel could be an issue. Moreover, PFAS coatings are the most promising alternative to lead in bearings being investigated as a lead-free alternative to comply to the Restriction of Hazardous Substances (RoHS) Directive.

Due to the specificity, high reliability and safety, across a long lifespan (up to 40 years for certain applications) it is challenging to develop a PFAS-free alternative with the necessary technical performances to PFAS. Moreover EUROMOT members rely on PFAS manufacturers to develop PFAS-free alternatives. These critical applications require extensive and specific qualifications to comply to current regulation while ensuring safe operations. EUROMOT members have identified that more than 13.5 years will be needed from when a PFAS-free alternative is made available for the transition.

EUROMOT suggests changes to the proposed wording for Derogation 2.10, to ensure the critical systems they supply are able to support the critical infrastructures as highlighted by this report. Changes to the original wording are highlighted in bold.

<u>Derogation 2.10</u> "Applications affecting the proper functioning related to the safety and **reliability** of **Internal Combustion Engine systems and Alternative Powertrain systems, and affecting the safety of humans or reliability of equipment** until 13.5 years after entry into force".

EUROMOT member products have long lifespans and therefore without a derogation which permits the manufacture and use of spares, repairs and remanufacturing, will result in the early disposal of many products. It is also important that there is a proportionate process to allow derogations to be extended if needed.

EUROMOT members are not battery manufacturers however due to the critical function batteries provide to their products that they support, there is a need for a derogation to allow the continued use of PFAS in batteries. The technical details of their use is outlined by feedback provided by the likes of EUROBAT and RECHARGE. In addition to this, EUROMOT members are manufacturers of battery packaging with the technical details of this outlined within the report.

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ABBREVIATIONS AND ACRONYMS

CARB	California Air Resources Board
EPA	Environmental Protection Agency
FKM	Fluorine Kautschuk Material (Fluorine Rubber)
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
HFO	Hydrofluoroolefins
HNBR	Nitrile-butadiene Rubber
IC	Internal Combustion
ICE	Internal Combustion Engine
FEP	Fluorinated ethylene propylene
FFKM	Perfluoroelastomer
NBR	Nitrile Rubber
NRMM	Non-Road Mobile Machinery
PFA	Perfluoroalkoxy alkanes
PFAS	Per- and Polyfluoroalkyl substances
PFPE	Perfluoropolyether
PTFE	Polytetrafluoroethylene
PVD	Polyvinyl fluoride
PVDF	Polyvinylidene fluoride
PVF	Polyvinyl fluoride
REACH	Registration, Evaluation, Authorisation of Chemicals
SDS	Safety Datasheet
VMQ	Silicone Rubber Vinyl Methyl Silicone
XNBR	Carboxylated nitrile rubber

1 INTRODUCTION

RINA Tech UK Limited (RINA) was requested by the European Association of Internal Combustion Engine Manufacturer (EUROMOT) to gather information from members to support the stakeholder engagement currently being undertaken for Per- and Polyfluoroalkyl substances (PFAS) under the REACH restriction proposal[1]. Owing to the wide range of desirable physical and chemical properties PFAS offer, they are used in a wide variety of products produced by EUROMOT members outlined in this report.

Although the majority of EUROMOT members are able to identify where PFAS substances are used in their products, there are still some challenges for EUROMOT members. PFAS is not separately and distinctly stated internationally on Safety Datasheets (SDS), which only apply to chemicals. Most of the substances falling under the PFAS definition are not classified as hazardous under Classification, Labelling and Packaging Regulation (CLP) or part of the Candidate List of Substances of Very High Concern under the Registration, Evaluation, Authorisation and restriction of Chemicals Regulation (REACH) and therefore there is no obligation to disclose the presence of PFAS substances along the supply chain. Where the presence of PFAS is in articles this would not in general be declarable to a manufacturer. This is especially challenging when seeking alternatives across the global market, as it can be difficult to ensure that the alternatives being researched are not themselves PFAS. It will take time to work through supply chains to discover precisely what substance is being used in many cases, and further time to establish what could be used as alternatives. Many respondents cannot quantify how long this will take but is likely to be an effort that will require multiple years.

1.1 Profile of the EUROMOT Membership

EUROMOT is the **European Association of Internal Combustion Engine and Alternative Powertrain manufacturers**. Representing the key global manufacturers for over 30 years, EUROMOT provides an unparalleled heritage and hub of expertise for businesses, authorities, regulators, and public stakeholders worldwide, partnering with major sector associations and institutions for sustainable innovation and comprises of **37 members**.

EUROMOT's mission strives to drive smart and gold standard global regulations for sustainable mobile machinery, marine and stationary applications to shape the technologies and markets of the future.

In addition delivering dependable power for society at high energy conversion efficiency with low emissions remains a key objective of EUROMOT member companies. EUROMOT asserts internal combustion engines and alternative powertrains are a key enabler to address the additional societal need for decarbonisation across multiple industry sectors. This can be achieved by continuing to advance the development of highly efficient energy conversion systems capable of operating on low and net-zero greenhouse gas energy carriers.

Products manufactured by EUROMOT members, such as those outlined in Figure 1 enable the successful operation of fundamental infrastructures such as those listed in Table 1-1.

[1] Annex XV reporting format 040615 (europa.eu)

Figure 1 EUROMOT members

Applications are to be found in a number of different industries with examples outlined in Table 1-1.

Table 1-1 Examples of EUROMOT uses.

Type of Engine	Indicative Uses
Internal combustion engine systems (A heat engine where the combustion of the fuel with an oxidiser occurs in a combustion chamber transforming the chemical energy resulting from this reaction into the kinetic energy needed as a propeller, motor, or power source)	• Agricultural, forestry and gardening equipment, • Construction equipment including heavy duty machinery for material handling and preparation, • Firefighting equipment and rescue equipment, • Auxiliary generators and water pumps for hospitals and rescue missions, • Power generation equipment, • Oil and gas exploration equipment, • Marine engines for passenger and cargo ships, • Rail and road transport equipment, • Mining equipment, • Telecom infrastructure, and • Uninterruptable power system (UPS) installations and generators installed temporarily on site.
Hybrid engine systems (Engine that combines the energy sourced from one or more combustion engines and an electric engines)	• Municipal waste collection equipment, • Air and gas compressors for industrial and personal use, • Irrigation systems for agriculture, • Outdoor power products for landscaping, • Hybrid electric and hydrogen fuel cells, and • Marine power trains.
Electric engine systems	• Airport waste collection equipment, • Auxiliary generators and alternative powertrains,

Type of Engine	Indicative Uses
(Class of devices that convert electrical energy into mechanical energy)	• Alternative power transport equipment for green energy transition, and • Outdoor portable (corded or cordless) power products for gardening, landscaping, and construction.

Additional information on EUROMOT's mission and membership can be found on their website https://www.euromot.eu/.

1.2 Importance to Society

EUROMOT member companies design and manufacture safe, reliable, high-quality, and high-performance products. The types of products EUROMOT members produce are a combination of internal combustion engines which rely upon the mechanical power derived from the combustion process in the cell to provide the necessary drive, as well as electric and hybrid powered system which are referred to as 'alternative powertrains'. EUROMOT's working groups are pioneering innovations in alternative powertrains including hybrid electric and hydrogen fuel cells enabling the alternative energy transitions.

EUROMOT member products are extremely complex, with Figure 2 and Figure 3 showing only a part of a system that is manufactured by EUROMOT members. Internal combustion engines typically have between 1200 to over 2000 components, and electric engines have more than 200 parts, the scale of the number of components gives an insight in the high complexity of those devices. Moreover, the products of the EUROMOT members are highly integrated complete systems for power supply which are adapted to the respective application, such as the quality of the operating fuels and the operating conditions (temperature, humidity, harsh chemical environment), in order to fulfil the required work task.

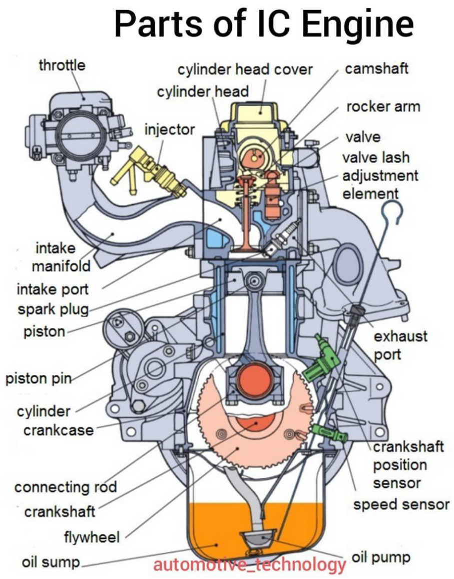


Figure 2 Parts of an Internal Combustion (IC) Engine

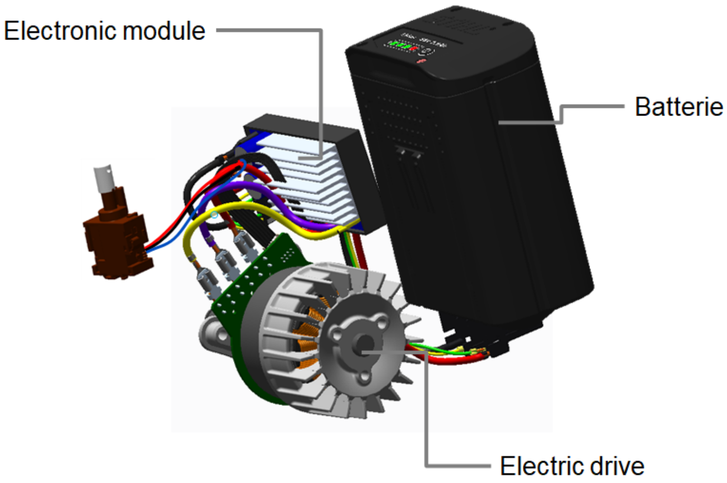


Figure 3 Parts of an electric powertrain (chain saw)[2]

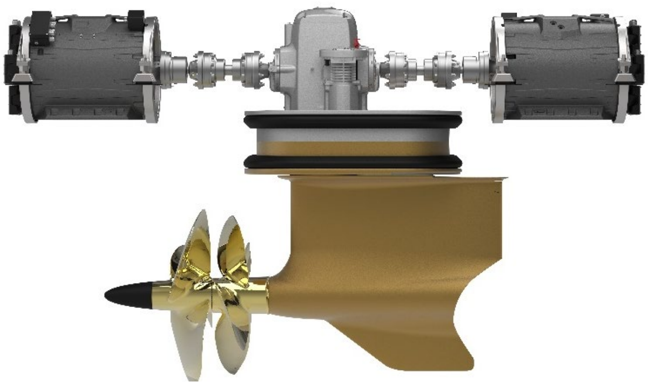


Figure 4 Marine electric power system

[2] Electric power train

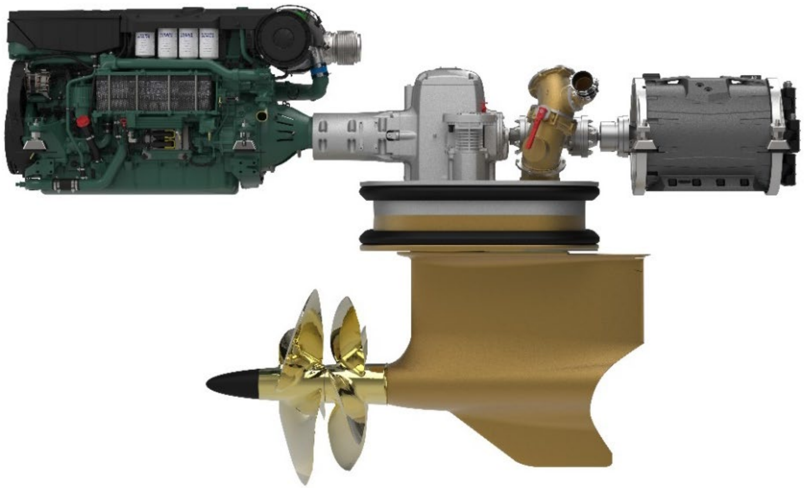


Figure 5 Marine Hybrid power system

EUROMOT's member's engines must comply with EU emissions legislation[3] and so are designed with an array of electrical controls with sensors and actuators to maximise performance with minimum emissions. Any changes to these designs must be approved by an EU Notified Body before the modified engine can be used in the EU. Modern advanced internal combustion engines and alternative powertrains are in continuous development to meet customer requirements and have played a central role in modern social and economic development. Engine manufacturers have for more than 50 years, invested billions of euros into new technologies that dramatically reduce the environmental impact of using those technologies by reducing emissions and improving engine system efficiency. This has been achieved while also working to minimise operating costs and increase engines efficiency to retain their role as society's most economical and versatile power source.

EUROMOT products are key technologies to enable operation activities in a multitude of fields including infrastructures and constructions, agriculture, energy production and distribution, communication infrastructures and mining. With examples of EUROMOT members products provided in the following figures.

[3] https://single-market-economy.ec.europa.eu/sectors/automotive-industry/environmental-protection/non-road-mobile-machinery_en#:~:text=The%20new%20NRMM%20Regulation,engines%20on%20the%20EU%20market.

Figure 6 Generator Set[4]

Figure 7 Irrigation Pump[4]

Figure 8 Fire pump[4]

Figure 9 Screener[4]

Figure 10 Forestry equipment[5]

Figure 11 Farm tractor[5]

[4] Images provided by EUROMOT members.

[5] https://www.euromot.eu/our-industry/nonroad-mobile-machinery/

Figure 12 Cargo ships[6]

Figure 13 Airport equipment[6]

Figure 14 Lawn mower[5]

Figure 15 Bush cutter[5]

Figure 16 Excavator[6]

[6] https://www.euromot.eu/news/euromot-celebrates-30-years-of-imo-membership/

1.3 Reporting Methodology

PFAS are used as substances, mixtures and polymers for components and in manufacturing processes, and facilities infrastructure. A questionnaire was devised and circulated to the EUROMOT membership by RINA on April 14th, 2023.

The responses from the questionnaire were collated and analysed for common themes, in order to give a representation of the whole membership. RINA reviewed all of the responses and categorised them to enable the results to be summarised.

The information shared by EUROMOT members in this report provides a snapshot at the point of the information being gathered. It is understood that many EUROMOT members are still developing their strategies and responses to PFAS concerns, and as such have not been able to answer all of the questions asked at this time. It is to be expected, therefore, that views may change or develop with time as more work is done and as requirements emerge.

All timelines are assumed to result in the successful identification of parameter(s) in question the first time that tests are completed. If the test is not successful, resulting in tests having to be repeated or the discovery that a potential alternative can no longer be considered part way through its development, the timelines for qualification will be longer than outlined within this report. Due to the nature of these impacts being unpredictable in nature and efforts expended to ensure that test failure is not observed at all points, the impact of this type of outcome cannot be quantified.

2 PFAS SUBSTANCE IDENTIFICATION

To date EUROMOT members have identified more than 40 different PFAS substances, with polytetrafluoroethylene (PTFE) being the most common PFAS used, in more than 1900 components with the key uses outlined in Table 2-1 with a more detailed breakdown in Appendix A. The assessment of PFAS to identify where it is used within EUROMOT members equipment is still ongoing, with certain challenges in identifying all PFAS used as outlined after the table.

Table 2-1 PFAS substances identified by EUROMOT members and uses.

PFAS substances	Uses
• 1-Butanesulfonic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, potassium salt (1:1); • Ammonium-pentadecafluorooctanoate • Fluorovinylmethylsiloxane rubber / fluorosilicon rubber • Perfluoropolyether • Perfluoroalkoxy alkanes • PTFE	Systems: Connector assemblies in electric vehicles, switches, spark unit and heaters.
• 1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene • 4,4'-(2,2,2-Trifluoro-1-(trifluoromethyl)ethylidene)diphenol • Ethene, tetrafluoro-, homopolymer • Tetrafluoroethylene propylene • Fluorine rubber (FKM) • Fluorovinylmethylsiloxane rubber / fluorosilicon rubber • fluorocarbon rubber • Perfluoropolyether • Phenol, 4,4'-[2,2,2-trifluoro-1-(trifluoromethyl)ethylidene]bis-	Components uses: Filters, hoses, hydraulics, internal and external cases, plugs, seals, O-rings, vapor separator, valves, manifolds, gaskets, bushes and gauges

PFAS substances	Uses
• Propane, 1,1,1,2,2,3,3-heptafluoro-3-((trifluoroethenyl)oxy)-, polymer • Propanoyl fluoride, 2,3,3,3-tetrafluoro-2 • Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene • PTFE • Polyvinylidene fluoride (PVDF)/ polyvinyl fluoride (PVF)	
• 1-Hexene, 3,3,4,4,5,5,6,6,6-nonafluoro-, polymer with ethene and tetrafluoroethene, • 1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene • 1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene • Ethene, tetrafluoro-, homopolymer • Fluorovinylmethylsiloxane rubber / fluorosilicon rubber • Perfluoroalkoxy alkanes • Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], .alpha.-(1,1,2,2,2-pentafluoroethyl)-.omega.-[tetrafluoro(trifluoromethyl)ethoxy]- • Propanoyl fluoride, 2,3,3,3-tetrafluoro-2 • Propanoyl fluoride, 2,3,3,3-tetrafluoro-2-(1,1,2,3,3,3-hexafluoro-2-(heptafluoropropoxy)propoxy)-, polymer with trifluoro(trifluoromethyl)oxirane, reaction products with 3-(ethenyldimethylsilyl)-N-methylbenzenamine • Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene • PTFE • PVDF/PVF	Electronics uses: Drive and power trains, controls and energy systems, vehicle equipment, sensors, cables, high voltage cables, socket assembly, PCBs, electronic assembly, ECU assembly, display assembly, electric motors, and batteries.
• 1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene • Ethene, tetrafluoro-, homopolymer • fluorocarbon rubber • Hydrofluorocarbons & hydrofluoroolefins • Perfluoroalkoxy alkanes • Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], .alpha.-(1,1,2,2,2-pentafluoroethyl)-.omega.-[tetrafluoro(trifluoromethyl)ethoxy]- • PTFE • PVDF/PVF • 2,3,3,3, tetrafluoropropen (R-1234yf)	Chemicals uses: Additives in rubber, lubricants, coating, refrigerant fluids, and greases.

As mentioned above, the substances outlined in Table 2-1 are only those identified to date by EUROMOT members and there are many more substances yet to be identified due to effort which are still on going. The effort to gather PFAS information although already has started in many EUROMOT member companies does generally take more than 2 years to undertake, as outlined in Table 2-2.

Table 2-2 Timeline to identify PFAS materials in EUROMOT products and processes.

Activity	Time
Identification of potentially PFAS containing parts and subcomponents	12+ months
Supplier communication and training	3 months
Request data from suppliers	12 months
Supplier data review to check accuracy	1 month
Validate PFAS presence with supplier	1 month
Total:	**2.5 years**

Identification takes extensive effort as many PFAS used in mixtures have not been classified as hazardous per the Globally Harmonised System for classification and labelling. In addition, they have not been listed as Substances of Very High Concern (SVHC) or included on the Candidate List of SVHC for Authorisation. Therefore, many PFAS are not shown on safety data sheets even though the substance is present.
In addition to this, chemical supplier companies invest significant time, money, and resources into developing proprietary chemicals to meet the exacting client requirements. EUROMOT are not chemicals manufacturers and have to rely on suppliers for information which is often protected by intellectual property of the chemical supplier, so the identification of the specific substance is not communicated to customers as companies need to ensure that their investment is protected. Releasing information about certain chemicals to the public would give competitors an unfair advantage and is likely to cause substantial harm to the company's competitive market position. Therefore, this information is divulged only when mandated by legislation such as the REACH and CLP Regulations, which is not currently required for most PFAS.

Moreover, when PFAS are used as articles or articles in complex objects, the parts suppliers are currently under no regulatory obligation to highlight the presence of PFAS. As a result of these various factors the discovery of PFAS uses in engine systems is extremely challenging.

3 TECHNICAL REQUIREMENTS AND ANALYSIS OF ALTERNATIVES

EUROMOT applications often require demanding technical requirements due to the challenging environments in which those types of machineries operate. Manufacturers design their products to operate for decades under extremely harsh, demanding, and arduous work environments. Materials, parts, and components need to meet rigorous design and testing requirements to ensure critical functions operate safely, continuously, and effectively on the jobsite. With their many useful chemical and physical traits, PFAS provide many crucial characteristics necessary to meet various equipment design challenges such as high temperature and vibration resistance, chemical stability in harsh environments, durability, light weight, and high reliability over a prolonged time.

The following sections outline each of these requirements in detail, bringing forth specific requirements from combustion engines, however the same requirements also apply to electrical and hybrid engines as they also are exposed to very similar requirements.

3.1 Operational Environment

EUROMOT members' equipment are often required to work in harsh and dirty environments where appropriate sealing is necessary to prevent ingress of particulates and contamination on sensitive critical components that could result in the failure or down time of critical devices. Examples of products operating in such environments include equipment in quarries, mines, or construction sites, where high levels of contamination from particles of dust, debris, and pollutant fumes are present. Moreover those devices are often required to operate outdoors so experience very large temperature changes, unfavourable weather conditions occur or are subject to salt spray when used in marine environments. The ingress of contamination in those critical devices would result in component corrosion and failure of critical electronic components. Under those conditions a sufficiently clean environment such that particles will not be introduced to the engine, especially during maintenance, is impossible. It is therefore essential that suitable materials are selected for the design of the equipment. The following issues could occur due to ingress of contamination in the system:

- Ingress of moisture and / or salt spray in the system with the result of corrosion of the metal parts of the device and failure of the electronic components of the device by short circuit. Many safety features are controlled by the electronics and a failure of those component would increase the risk of harm to the operators.
- Ingress of particles that can deposit on a bearing surface resulting in increased friction and higher localised temperatures in addition to premature wear of bearings.
- If a fuel is used in the system, the ingress of pollution or particles could get in contact with the fluid and result in its contamination. The contamination of the combustion fluid can result in the formation of additional combustion by-products and fumes of unknown and potentially harmful nature.

To prevent exposure of critical electronic parts to dust and dirt ingress and ensure pressure equalisation, membranes are integrated in the design. Protective vents and membranes utilising FKM, are designed to be highly reliable and work in challenging environments for significant lengths of time (typically 10-15 years or longer). By using PFAS containing vents and membranes, the potential disruptions due to contamination of the device is prevented by ensuring the reliability and functionality of critical devices. Whenever a device is subject to contamination there is a serious risk of its complete failure that would significantly shorten its life. The use of PFAS materials as a reliable and durable membrane material, reduces the environmental waste that would derive from premature failures and extend the device life expectancy. Failure of those devices can introduce significant risk to the safety of operators and nearby workers.

PFAS are critical to such filtration and membranes devices due to their ability to form thin structures that retain their mechanical properties, therefore forming a porous structure. This devised structure allows gas permeation and thus pressure equalisation while preventing the ingress of liquid contamination due to their hydrophobicity and oleophobic properties. The membrane must perform its function even after long term exposure to high humidity and high temperature, and therefore need to present stability against hydrolysis. To ensure the effectiveness of the membrane to water ingress membranes such as this are qualified to standards which measure the water protection (both submersion and high-pressure spray) and rated against the following ingress protection (IP) ratings - IPx7, 8, 4, 6k, 9k for water ingress, and IP6x for dust protection. As moisture of ingress in the device could result in serious repercussion on the reliability of the device typical industry requirement for humidity resistance are strictly outlined in IEC 60068-2-78 standard. To achieve compliance to those requirements the industry heavily relies on the use of PFAS substances.

Due to the demanding conditions of the operating environment of those devices, lubrication is required in particular components that is resistant to both high temperatures and a dirty environment. In those instances, the use of dry lubrication allows resistance to friction over prolonged periods of time without requiring re application of a fluid or grease as a lubricant. Components requiring this, such as bearing are often in hard to access locations in the engine system where access is not possible and/or tight geometry control would not permit other types of lubrication. The use of a traditional lubrication system is not suitable under conditions such as:

- Engines which require a total displacement of ≥15 litres under extreme high load operations, the use of a traditional lubricant in conditions of high pressure and shear stress would result in bleeding of the lubricant, which is the term describing the separating of the phases composing the lubricant. This would result in inappropriate function of the lubricant, localised high temperature and possible hardening of the lubricant in situ that would result in prevention of the relative movement of the parts.

- Contamination of the fuel from a traditional lubricant, this issue can easily be prevented by the use of a PFAS dry lubricant which is a thin coating applied directly on the bearing. The flow characteristics of the PFAS coating are such that it does not migrate outside of the limited area it is applied to.

- Engines which require a quick (<10 seconds) start, use parts with dry lubrication and lubricant to be able to achieve such quick starts and its high reliability of starting each time.

PFAS provides seizure resistant, resistance to damage, conformability, embeddability, fatigue strength, flexibility, chemical resistance, suitable manufacturing tolerances and resistance to cold temperature and limited lubrication during start-up. All of which are essential technical parameters considering the end applications EUROMOT members product serve.

No PFAS-free materials have been identified as potential alternative to PTFE in protective vents applications, membranes, and dry lubricants applications. The inherent low-surface energy of PFAS materials that provides the important contamination resistance properties in this application as well as the dry lubricant properties cannot be matched by PFAS-free materials. In addition, the complexity of EUROMOT devices requires a combination of properties that currently cannot be matched by non-PFAS materials (temperature, humidity, salt fog, corrosive gas, chemical resistance in combination with reliable pressure equalisation function and ingress protection).

3.2 Chemical Resistance

EUROMOT applications are designed to work for extended period of time, with high reliability requirements over the course of a timeframe of up to 40 years. As discussed previously, in engine applications, components have to withstand an array of different conditions including exposure to harsh chemicals and cycles of high temperatures for prolonged period of time. The implications of those requirements are that the materials selected for those components need to show compatibility with multiple conditions.

Surface Tension

Fluoropolymers are characterised by their low surface tension which means that they offer excellent chemical resistance to a wider variety of chemicals. EUROMOT members products are often exposed to harsh chemicals such as alkaline engine oil, which has a pH of 9, of fuels that can be blends of ethanol and aromatic compounds such as toluene or ethyl benzene. As the end use applications of EUROMOT systems include industrial and farming applications, as well as exposure to salt fog when installations are located offshore or close to the sea, resistance to harsh chemical conditions need to be ensured. For example, exhaust gas contains sulphur and nitrogen oxides that when condensed into humid air or water create sulphuric acid and nitric acid with pH near 1. In the Exhaust Gas Recirculation loop FKM is used as the seal material in junctions due to its compatibility with strong acids.

Another application exposed to low pH environment is the exhaust gas systems where acid condensation can occur. Acidic environment affects steam seals and sensors therefore appropriate sealing needs to be ensured. The gas will pass the combustion chamber piston and enter the ventilation system, exposing the whole system to the low pH condensation product when the engine is off. Engine oils are designed to remove the traces of water and gases, however it is not a 100% efficient process and oil degrades, so all seals (such as crank case seals) must be able to withstand acid containing condensation as well as temperature fluctuations and wear.

For critical applications a combination chemical resistance and high temperature resistance have to be ensured. For example cylinder head gaskets, where the component is exposed to coolant additives like 2-ethyl hexanoic acid, and carboxylic acids, with exposure to temperatures between 150 and 175°C, PFAS-free options have been shown to shrink and lead to leakage of the seal at temperature above 135°C leaving FKM as the only reliable option for this application.

Seal resistance

Toxic and flammable chemicals are used at high temperatures and pressures in EUROMOT engines, for example in engine fuel systems. In case of leakage there is a risk to operators from the exposure to such substances as well as a risk of the substances catching fire. In engines there are areas that can reach a temperature of up to 550°C, if fuel was to leak into such areas this would lead to fire. No alternatives are available for FFKM and FKM sealings with adequate temperature (up to 280°C) and chemical resistance.

Many of the seals used in EUROMOT members equipment require chemical resistance against aggressive chemicals such as fuels and engine oils, with a minimum swelling rate (< 25% in the "worst case"). Higher swelling rates would result in a decreased tensile strength that will induce the formation of cracks due to mechanical stress and result in the failure of the seal.

Other non-PFAS alternative elastomer materials are commercially available as seals, such as those listed in Table 3-1, the most commonly knows of which are nitrile rubber (NBR), nitrile-butadiene rubber (HNBR) or carboxylated nitrile rubber (XNBR). However the alternatives do not offer the same technical performance when compared to FFKM listed at the bottom of Table 3-1 and as such would result in the failure of the seal as they are expected to be exposed to all of these environments and substances. In addition to this NBR, HNBR or XNBR are not resistant to the presence of ozone, as it is known that even trace levels of ozone in air will attack the double bond of the rubber chain resulting in its degradation by ozone cracking. Moreover, these rubbers are not media resistant inducing higher friction in the system resulting in higher variance in engine efficiency and higher carbon dioxide emissions.

Table 3-1 Resistance properties of elastomers exposed to different mediums, with fluoropolymers provided for comparison highlighted by the red box.[7]

Type of elastomer/	Standard	Engine oil Lubricating grease	Diesel fuel	Corro-sion inhibitor/ anti-freeze	Cool-ant with corrosion inhibitor	Corro-sion inhibitor oil emulsified	Sea-water	Hot air (200 °C)	Envir. ozone Sunlight	Hot oily air
Nitrile butadiene rubber NBR / black	MMN 375	++	++	0	0	0	+	-	-	+
Hydrogenated nitrile butadiene rubber HNBR / black	MTL 5078	++	++	+	+	+	+	-	0	+
Fluorocarbon rubber bisphenolic FKM / red	MMN 387	++	++	0	0	0	++	+	++	+
Fluorocarbon rubber bisphenolic FKM / brown	MTL 5087	++	++	0	0	0	++	++	++	++
Fluorocarbon rubber peroxidic FKM / black	MTL 5076	++	++	+	+	+	++	+	++	+
Fluorocarbon rubber peroxidic FKM / black	MTL 5083	++	++	+	+	+	++	+	++	+
Silicone rubber VMQ	-	-	-	+	+	-	+	++	++	-
Chloroprene rubber CR	MTL 5024	0	0	0	0	-	+	-	+	-
Acrylate rubber ACM	-	++	+	-	-	-	-	-	+	0
Chlorinated polyethylene rubber CM ("AQP")	-	++	++	+	+	+	+	+	+	+
Natural rubber/ styrene butadiene rubber NR/SBR	MTL 5099	-	-	0	0	-	+	-	-	-
Perfluoroelastomer FFKM	MTL 5109A	++	++	+	+	+	+	+++	++	+++
	MTL 5109B	++	++	++	++	++	++	++	++	++

+++ Extremely high resistance
++ Very good resistance
\+ Good resistance
0 Resistant to a degree
\- Poor resistance

As highlighted in Table 3-1 there are currently no polymers with characteristics comparable to PFAS materials. This is due to the vast array of conditions to which the components need to withstand (contact with grease, fuel, corrosion inhibitors and additives as well as marine environment, high temperature and ozone). Some PFAS-free rubbers are resistant to some of these, but none are resistant to them all. Moreover, some fuels like DIN EN 228 (Otto-fuel) used in marine applications, provides even harsher

[7] Günter Walter, Kunststoffe und Elastomere in Kraftfahrzeugen, 1985, Kohlhammer Verlag, Stuttgart.

operating conditions due to the higher concentration of aromatics and would not be compatible with PFAS-free alternatives such as NBR.

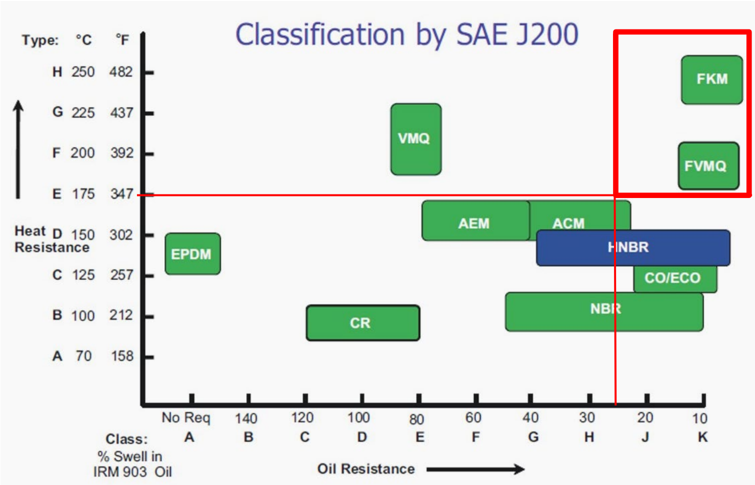


Figure 17 Elastomers classification by SAE J200, heat resistance vs oil resistance.[8]

Figure 17, represents the classification for rubber materials according to the properties of rubber materials (SAE J200) to provide a comparison between PFAS materials and PFAS-free alternatives. With consideration to the requirements for EUROMOT devices to operate at temperatures higher than 175°C with a maximum swelling of 25% when in contact with engine oils, the only materials fulfilling those requirements are FKM and fluorosilicone (FVMQ), as highlighted in the red box.

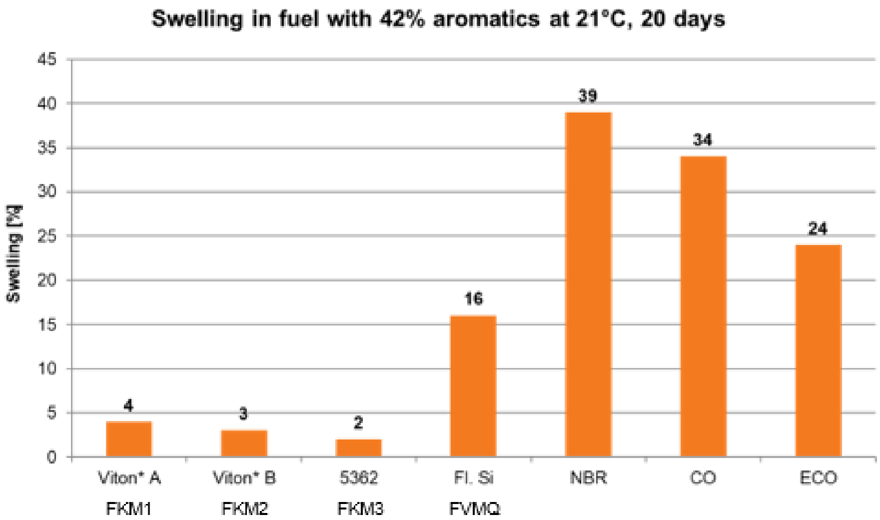


Figure 18 Volume swelling % of different materials exposed to fuel.[9]

[8] "The Vanderbilt Rubber Handbook", Fourteen Edition, edited by Martin F. Sheridan.

[9] "Resistance of elastomers to alcohol-containing fuels", A. Nersasian, J.D. MacLachlan, E.I. du Pont de Nemours, Inc.

Figure 18 shows a comparison of swelling characteristics of different materials when exposed to 42% aromatic fuel. As highlighted in the graph, PFAS-free alternatives present swelling above the allowed limit of 25% and are therefore not suitable.

One such example are O-rings and fuel hoses and their uses in fuel systems which utilise FKM to prevent unwanted fuel leakage at the customer's site over the product's service life and to ensure operational and functional safety. FKMs are characterized by excellent fuel resistance and low permeability with heat resistance until 280°C, while still maintaining its mechanical characteristics allowing a low compression rate of < 40% (at 175°C).

Other, commercially available elastomer materials like NBR, HNBR or XNBR contain plasticiser, which leads to hardening of the elastomer and shrinkage (because the plasticisers dissolve in the fuel), in applications such as those used in the fuel system this can lead to fuel leakage. In addition, due to the very high dynamic load, hoses are already subject to cracking due to the high stress, therefore resistance to the crack formation due to chemical incompatibility needs to be avoided as much as possible. Crack initiation on the surface due to chemical attack would act as a stress intensity factor for the propagation of cracks, especially for a components already subject to high loading. FKM presents optimal aging resistance where no cracks are present after long time storage in ozone atmosphere (500h, 40% elongation, 40°C). Other elastomer types are not an option due to the lack of fuel resistance (swelling rates are massively higher >100%, materials are compromised by the medium). As seen in Table 3-2, polymers that have comparable swelling and temperature resistance characteristics are not recommended to be used for O-ring or other sealing applications, due to the maximum compression set they can withstand and elongation characteristics at breakage. Moreover PFAS-free alternatives that have similar characteristics are not compatible with exposure to fuel, or resistance to ozone, therefore only PFAS substances are suitable for those applications.

Table 3-2 Characteristic values of different elastomers.[7]

Type of elastomer / coloration	O-ring material standard	O-ring application	Min. tensile strength at break (N/mm^2)	Elongation at break (%)	Hardness (Shore A)	Max. compression set (%)		Comments
Nitrile butadiene rubber NBR / black	MMN 375	Not for new designs	20	300 to 400	65 to 75	20 (20 °C /100h)	40 (100 °C /24h)	-
Hydrogenated nitrile butadiene rubber HNBR / black	-	Rotary seals	13	> 200	As per drawing	-	50 (125 °C /24h)	MTL5078 for molded parts MTL5099
Fluorocarbon rubber bisphenolic FKM / red	MMN 387	Standard application	10	130 to 250	65 to 75	15 (20 °C /100h)	20 (200 °C /24h)	-
Fluorocarbon rubber bisphenolic FKM / brown	MTL5087	High temperature in air/oil	10	> 130	75 to 85	15 (20 °C /100h)	15 (200 °C /24h)	MTL5087, low setting tendency
Fluorocarbon rubber peroxidic FKM / black	MTL5076	Coolant	15	130 to 250	65 to 75	25 (20 °C /100h)	30 (200 °C /24h)	Particularly resistant to coolant
Fluorocarbon rubber peroxidic FKM / black	MTL5083	Low temperature > -40 °C	10	> 130	65 to 75	15 (20 °C /100h)	20 (200 °C /24h)	Elastic at low temperature
Silicone rubber VMQ	Not for use as O-ring	Not for use as O-ring	4 to 9	100 to 400	30 to 80	-	25 (200 °C /70h)	Not oil-resistant (reference) MTL5099
Chloroprene rubber CR	Not for use as O-ring	Not for use as O-ring	7 to 25	100 to 800	20 to 90	-	80 (100 °C /70h)	Oil-resistant to a degree (reference) MTL5099
Acrylate rubber ACM	Not for use as O-ring	Not for use as O-ring	5 to 13	100 to 350	55 to 90	-	60 (150 °C /70h)	Reference
Chlorinated polyethylene rubber CM ("AQP")	Not for use as O-ring	Not for use as O-ring	Not specified	Not specified	Not specified	Not specified	Not specified	Up to 150°C US patent
Natural rubber/ styrene butadiene rubber NR/SBR	Not for use as O-ring	Not for use as O-ring	> 14	150 to 500	As per drawing	-	30 (70 °C /24h)	MTL5099
Perfluoroelastomer FFKM	MTL5109A	Very high temperature	15	> 150	70 to 80	No requirements	15 (200 °C /70h)	Very high component cost
	MTL5109B						30 (200 °C /70h)	Very high component cost increased resistance to coolant

3.3 Electrical and Thermal Resistance

Thermal Resistance

EUROMOT devices are used in a variety of different climates, from artic environments with temperatures that can reach many degrees below zero, to hot and humid tropical climates and deserts. Therefore most EUROMOT applications will have to withstand cycles of high and low temperatures during operations as they could be started in a cold climate and reach high spikes of operating temperatures. Applications have to withstand cycles of temperatures ranges as large as -70°C to +260°C, while retaining the same materials properties. Most PFAS-free polymers are too brittle at -70°C and decompose at the high temperature ranges experienced during operation.

PFAS substances have high thermal resistance over the long period EUROMOT members products operate, with indicative examples of how non-PFAS alternatives compare to PFAS containing alternatives outlined in Figure 19. Vibration environment in an engine poses an additional challenge in the investigation of a suitable substitute. Engines will vibrate for very long periods, and this can cause high frequency fatigue to components due to the repeated strain imposed. The mechanical alternating stress between joint components will make joints undergo cyclic tension and pressure, which may cause the generation, expansion, and extension of cracks. Those requirements need to be considered when seeking a PFAS-free material to ensure reliability of the device.

PFASs are the only substances that can maintain elastic properties at temperatures near 200°C. Other materials could lose their elastic properties and become brittle at higher temperatures resulting in failure of the seal.

Moreover PFAS materials provides insulation against noise and vibration due to their unique characteristic of store energy elastically and the ability of the material to dissipate stress through heat, above 175°C. As PFAS-free materials are not able to withstand such temperatures before being thermally oxidised and becoming brittle, PFAS substances are the only materials to ensure those requirements. Figure 19 shows the comparison of PFAS and PFAS-free materials for O-rings with relation to operating temperature and operating hours. For operating conditions of 18,000 hours, which is the minimum value for an O-ring, above a temperature of a 125°C, which is already on the lower end of what an engine component would experience, the only suitable material is FKM (highlighted in red).

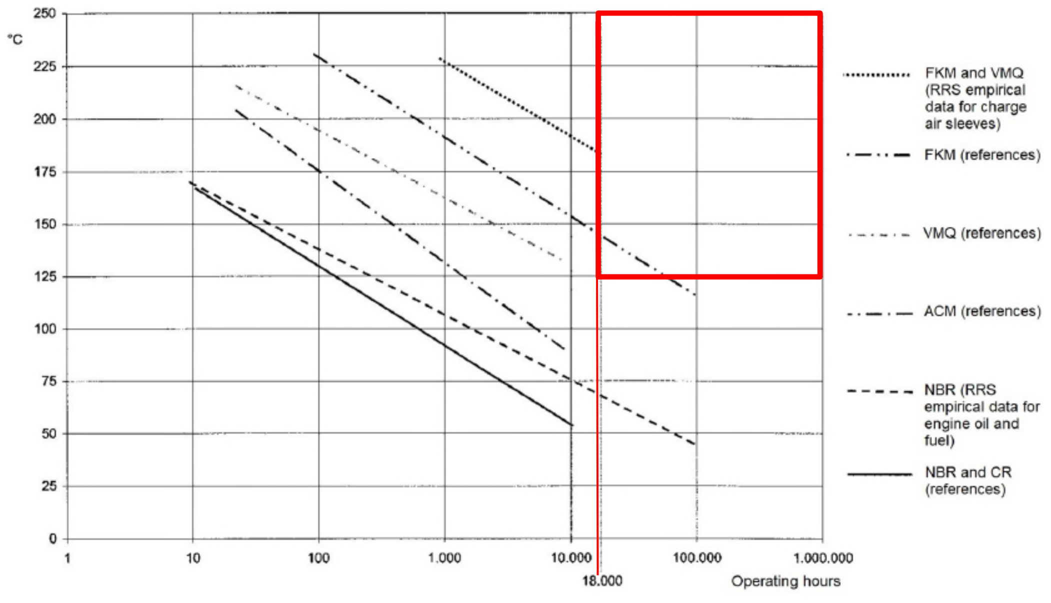


Figure 19 Maximum service life and operating temperatures in air. 18.000 hours is the minimum operating time for most O-rings.[10]

[10] VERSTÄNDIGUNGSNORM – EXPLANATORY STANDARD, Elastomers – Overview MTN5097 April 2023

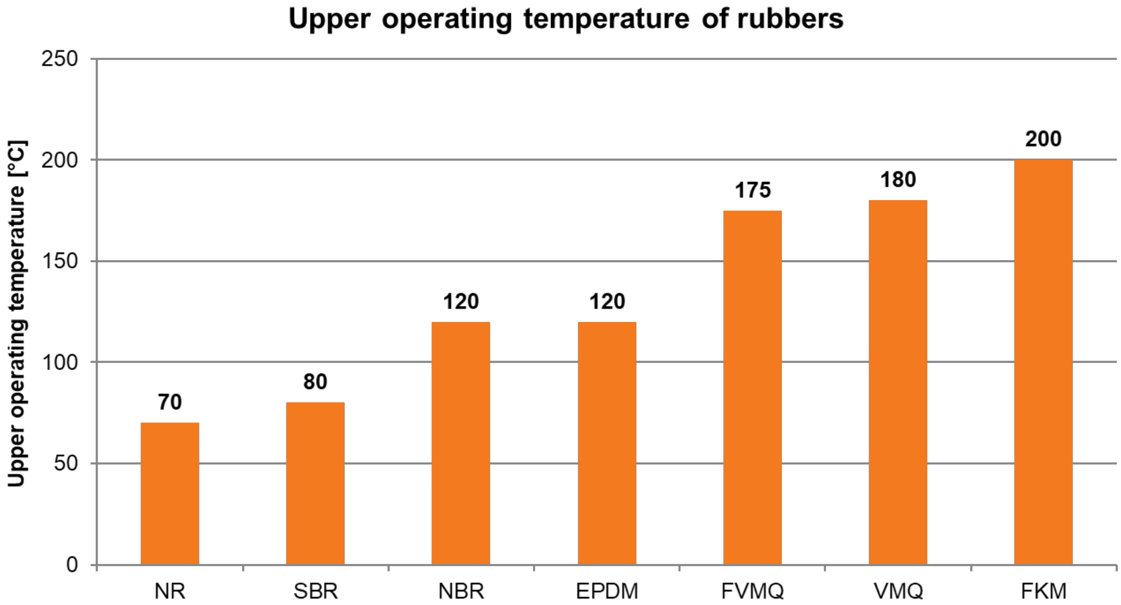


Figure 20 Upper operating temperature of rubbers.[11]

Electrical resistance

Cables and electrical insulation used in EUROMOT applications utilise PFAS substances in three keyways, stranded wire insulation, wrapping of wires and cable protection. Most cables consist of several wires which have to be isolated against each other and thus use an insulation layer (stranded wire isolation). Cables in engine and power train applications have to withstand exposure to high temperatures including temperature cycling, so the insulation layer needs to withstand these temperatures. An extreme example is with lambda probes that measure oxygen concentrations in hot exhaust gases. They also need to have low water vapor permeability due to the high humidity experienced in certain operation. In addition, they need high insulation resistance and non-flammable characteristic whilst maintaining a small diameter due to the size constraints of many devices.

Silicone, polyvinyl chloride, and polyurethane may be suggested as alternative to FEP and PTFE isolation layer for wires. However, these do not meet the same flammability requirements and have the potential to become brittle when the plasticizers migrate. Also, none of these can withstand the very low or very high temperatures that FEP and PTFE can operate. Silicone also has the concern that it is vapour permeable therefore, water can accumulate between the single strands which can lead to corrosion and malfunction of the device, as well as reducing the lifetime of the product. Silicone also has a lower insulation strength compared currently used PFAS such as FEP, which would require the insulation wall thickness of each wire to be increased. A thicker insulation wall would mean increased weight of the overall equipment which would likely result in higher CO_2 emissions for a mobile equipment and difficulties in handling for a handheld device that could result in safety concerns for the operator. This would result in lower usability performance. Other commercially available flexible wire insulation materials are also not stable at high temperatures and therefore, not suitable for those applications.

[11] : “Technisches Wissen“ Fa. REIFF

3.3.1 EUROMOT specific component requirements

The combination of technical characteristics of PFAS is what make them uniquely suited to their use in EUROMOT member products. The following case studies outline why these properties are so essential in EUROMOT member products.

Injection fuel manifolds

Components such as manifolds can be exposed to temperature spikes of greater than 200°C during operation and have to maintain appropriate flexibility over the lifetime of the machine. They can be used in a number of different applications such professional chainsaws and cutting machines that can be used in applications such as firefighting and rescue applications, blowers, and cut-off machines. To ensure flexibility, geometric shapes are applied, e.g. stretch pleats which are realised by forced demoulding during the production process and are therefore critical in terms of production technology. Those parts are made of fluoroelastomers such as FKM, as the material properties do not change during the operation, when the device is subjected to temperature cycles and over the course of the lifetime of the machine. The flexibility must not change at low temperatures which could be experienced in northern countries and mountains regions with temperatures as low as -30°C to prevent the component from failing. Moreover the components need to be lightweight as those devices are portable and are required to be handled in challenging environments, therefore reducing the weight of the device is a fundamental design requirement. Failure of the manifold would result in the failure of the entire machine with repercussions on the safety of the users and of operations.

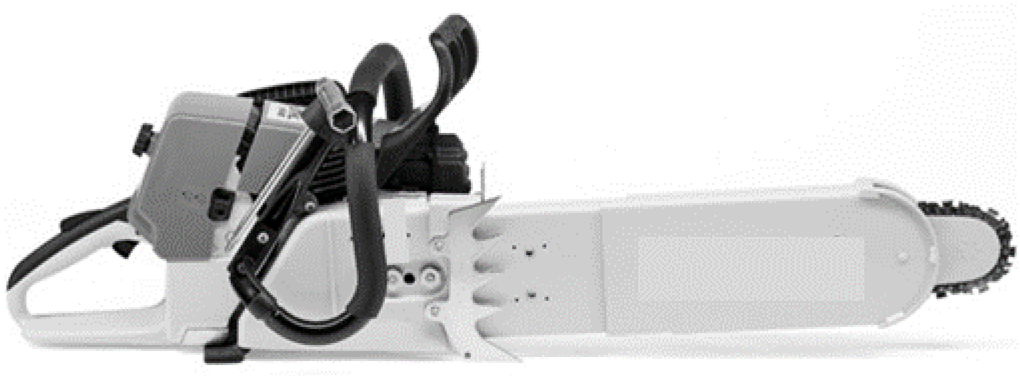


Figure 21 Rescue Saw is a professional saw exclusively designed for fire, rescue, and emergency services.

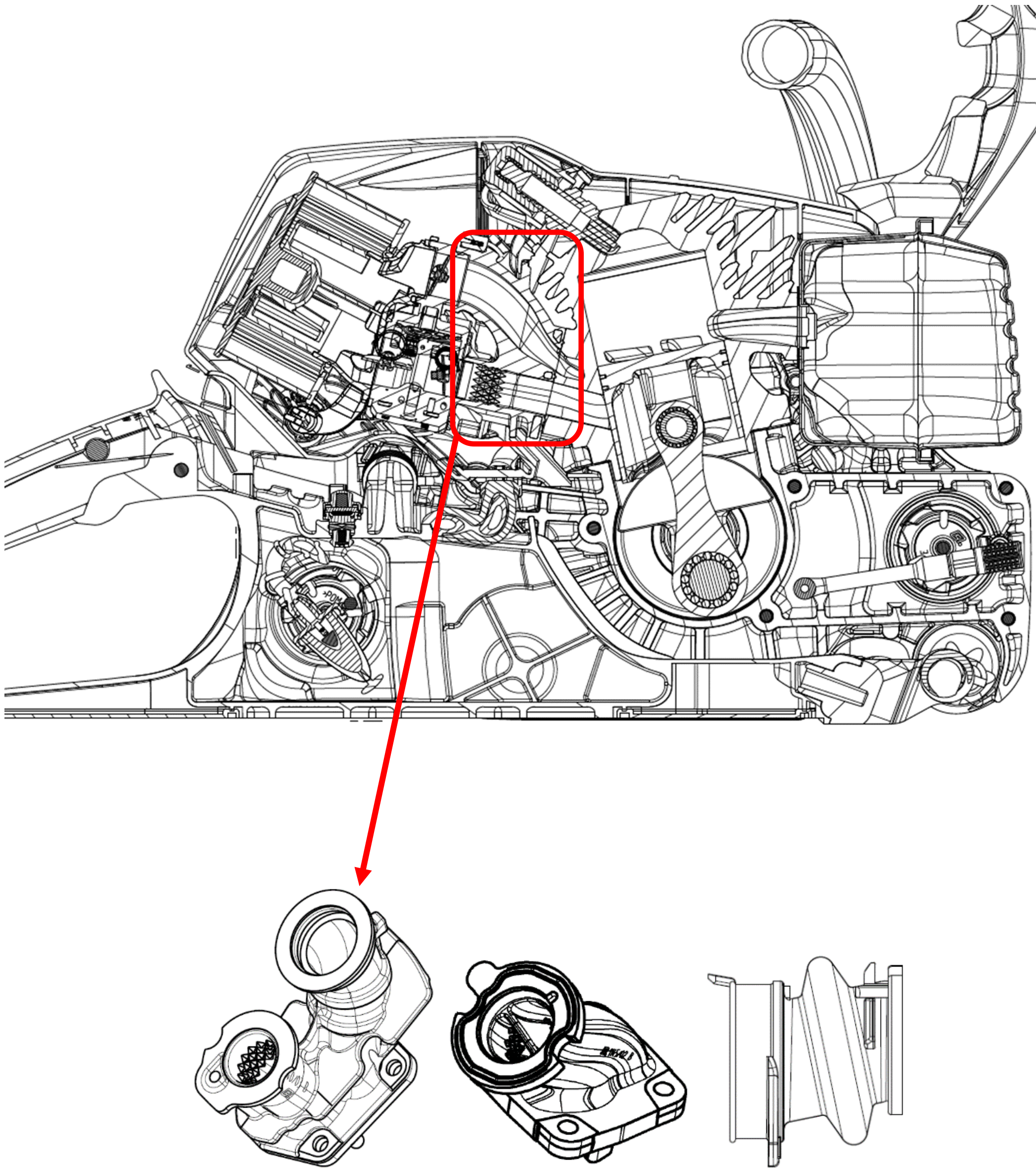
- 

Figure 22 Examples of manifold in a chainsaw and other handheld garden tools.

The manifold must be:

- Chemically resistant in case of contact with fuel with different ethanol proportions.
- Sufficiently rigid and of a suitable composition to ensure dimension stability after prolonged storage time that may result in drying of the fuel contained in the manifold and formation of a vacuum.
- Meet specific decoupling properties where it is used as a vibration-decoupling element to meet specific characteristics. In this instance the manifold has to be made of an elastic and temperature resistant elastomer. The polymer has to show specific hardness values as it should be suitable to withstand the vibration at the grips while keeping the functionality of the part with respect to fuel transmission.

Other available elastomer materials like NBR, HNBR or XNBR contain plasticisers, which leads to hardening of the component by extraction of plasticiser while they are subjected to high temperatures. Moreover, the maximum heat resistance is 120°C for NBR, 150°C for HNBR and XNBR, which would not be suitable for EUROMOT applications as the manifold would crack after a short time of the engine running.

Although VMQ is commonly used in high-temperature applications, it is not suitable as it is not compatible with fuel contact as it would swell and result in the collapse of the part in the event of change in pressure of the system and it would tear due to the loss of strength. It is to be expected that the high vibration frequency to which the system is subjected would result in the failure of the component within a short application time.

Shaft sealing

Shaft sealing rings are used to seal the crankshaft in combustion engines. The media from the crankshaft space and the mixture of fuel and oil, must be reliably sealed. The rotational speeds of the crankshafts are very high, which leads to a significant increase in temperature due to frictional heat (>160°C). In order to meet these requirements, FKM must be used as the sealing material. Other commercially available alternative elastomer materials such as NBR or HNBR are not sufficiently temperature and chemical resistant and become brittle after a short running time, which leads to machine damage and possible media leakage.

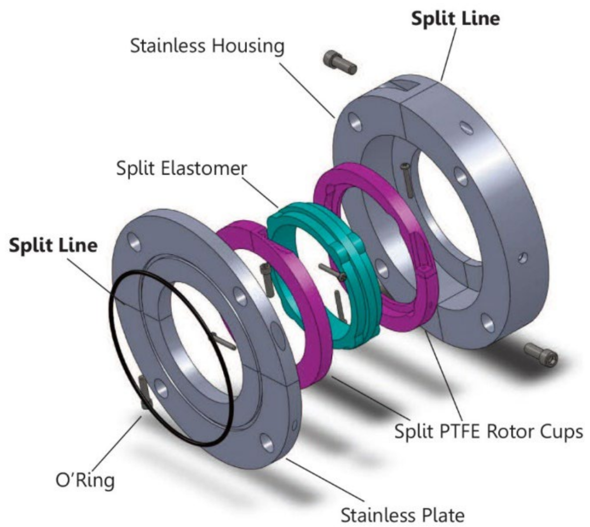


Figure 23 Example of rotary shaft sealing system using PTFE.[12]

Fuel hoses

The function of fuel hoses in motor appliances is to convey fuels with variable proportions of ethanol and aromatic compounds and the reliable sealing of the fuel tank bushings and nozzles. This function is currently fulfilled by hoses made of FKM, due to its properties of resistance to fuel contact without the addition of plasticisers. The material properties must not change over service life and different temperatures (between -30 and 250°C), to ensure safety of the user and of operation. Due to their very high engine speed and the tight installation space, chainsaws have a high-frequency load on the dynamically loaded components (e.g. the hoses, the manifold) and FKM elastomer is used to prevent dynamically caused microcracks, which can also lead to component breakage. In addition to the function

[12] https://cinchseal.com/what-are-rotary-shaft-seals/

of the hose, a low fuel evaporation from the hoses must also be ensured. FKM is the material of choice for compliance with low permeation rates related to California Air Resources Board (CARB) requirements as well. This requirement is related to emissions from small off-road engine fuel tanks which aims to reduce gas emissions from a combustion engine as well as preventing leakage of a flammable medium.

Other important applications of PFAS are carburators especially in the inlet needles component. This is particularly critical as a malfunction of the part would result in failure of the entire engine or piston or cylinder seizure with total damage of the engine, or lastly the engine would run in such a way that it does not fulfil the European emission legislation.

Many marine applications uses PFAS substances to achieve compliance to the safety of life at sea (SOLAS) convention for the marine commercial business.

Electrical cables

Electrical cable jackets are the outer layer of cable which have the function of protecting and isolating the inner sections. EUROMOT applications are classified as high temperature applications where often a classification of ISO 6722 Class D or higher is required, the diagram in Figure 24 of the insulation of a copper wire shows that the location of the PVF jacket. Those norms and requirements are required in automotive applications as well as in mining with even higher requirements for underground mining applications. The materials suitable for those applications are PTFE, fluorinated ethylene propylene, ethylene tetrafluoroethylene, or other PFAS polymers.

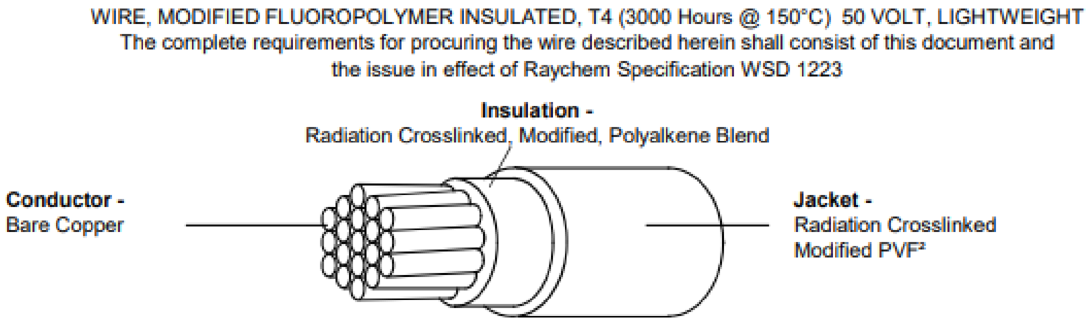


Figure 24 Wire Jacket insulation[13] diagram.

3.4 Low Friction

EUROMOT members manufacture products with a number of moving part that require lubrication during operation. Also, low friction in an engine leads to higher fuel efficiency, thus lower CO_2 emissions. Due to the geometry, inaccessibility and operating temperature of the harsh environments dry lubrication is often required. Lubrication through the use of lubricants, as well as dry lubrication provided by polymers, is also required in high power environment (very high loads on some systems, where otherwise metal to metal contact is not possible, even if greased).

The application of a PTFE coating is implemented for its low friction properties, particularly indicated for high reliability applications such as breaks and transmission systems due to their service temperature up to 250°C and tensile strength from 12 to 18 MPa. PTFE is used as a dry lubricant in components such as sliding guides, toothed racks, spindles, leadscrew, plunger balls, yokes, and rotators due to is minimal friction, longevity, and the inability to use greases which could drip contaminate the system.

[13] ISO 6722-2 wire jacket insulation diagram

PFAS substances have been investigated as lead-free alternatives for bearing overlay as an alternative to utilising lead through exemption 42 Annex III in the Restriction of Hazardous Substances (RoHS) Directive 2011/65. Currently lead is used as a thin coating (up to 90% lead) to provide a tribological interface between two moving parts which helps to prevent seizure and it can absorb debris which might otherwise cause engine failure. Lead in brass bearings provides seizure resistance, resistance to damage, conformability, embeddability, fatigue strength, flexibility, chemical resistance, impact of manufacturing tolerances and tolerance to cold temperature and limited lubrication during start-up. Bearing manufacturers in an effort to move to lead-free alternatives have identified PFAS as promising viable alternative. The restriction of PFAS will result in a significant setback on the timeframe for the investigation of viable alternatives to lead-free bearings.

3.5 Refrigerants

EUROMOT products often utilised refrigeration in its system as internal coolants to ensure the systems are able to operate in the demanding end applications they currently serve. For example, EUROMOT members engines operate in mining applications where it is not possible to control the operational temperature. Other large engines, such as for generators, can be located outside of protective environments and have the need to reliably operate. Refrigerants are for example used for electric propulsion systems in an ACU (Auxiliary Cooling Unit) primarily to cool the battery packs. Refrigerants are also used to cool the compartment of non-road mobile machinery which is essential to maintain a suitable working environment for the operators of such equipment which can be used in extremely hot environments.

EUROMOT members use a variety of PFAS containing refrigerants with HFC-134a and HFO-1234yf being the most commonly used. These substances are used as they are able to offer the combined properties of low vapour pressure, thermally stable over long time periods, low toxicity, non-flammable, and non-corrosive (therefore offering compatibility with metal, and plastic components). All other refrigerants are either banned under other legislation due to concerns over the global warming or ozone depleting potential or present an extreme risk of flammability. Potential alternatives such as ammonia, propane, or isobutane cannot be used in applications where there is an ignition source due to their flammability, thus precluding their use in engine systems as there is a high risk of catastrophic failure. There are other refrigerants such as carbon dioxide which may be suitable in some industries, however a significant amount of product redesign is required and often results in comparatively larger systems which may preclude their use in engines. The design of refrigeration systems is lengthy and technically challenging due to the need to meet stringent safety requirements. Therefore, the continued access to these substances will be required for a long period as is recognised under the EU F-Gas Regulation.

4 QUALIFICATION REQUIREMENTS

It is important that before any PFAS-free materials/components are incorporated into EUROMOT members products that they are tested by the producers of the equipment (usually EUROMOT suppliers) and then at a system level by EUROMOT members to ensure all relevant parameters are suitable. As PFAS are used in numerous ways, with more than **40+ substances across 1900 components**, with data being still gathered by EUROMOT members, it is important that sufficient time is permitted to allow these to be qualified. Engine development, as with any heavy machinery development, is an iterative process that can take several years to be completed before a new engine or engine component is able to be placed on the market. The timescale for redesign is difficult to estimate, as this depends on the engines design and the extent of any changes, and in some instances viable alternatives are not yet available. However, EUROMOT members have tried to estimate the necessary time based on the qualification undertaken for similar projects wherever possible.

Studies to ensure component quality and compliance with the combined tolerances of the system must be carried out. For example, agriculture machines can be used longer than 40 years and construction equipment can at times be operated over 20-30 years.

For EUROMOT's members to replace PFASs for all uses in EUROMOT's applications, first, their suppliers must carry out research on new components, then EUROMOT members will then have to test them in systems they are used in and for some components the systems as a part of the engine to ensure that they offer the necessary technical performance. The test phases tend to be undertaken in the following phases, with indicative tests outlined in each phase.

Laboratory testing undertaken by EUROMOT's supply chain on materials components. Fundamental properties of the material/component are tested in the first phase, including aspects such as chemical resistant to common substances, ozone resistance over long-term storage, or cold temperature crack testing. New components have to be designed and manufactured.

"On-engine" and field testing If a promising alternative is developed, then this must next be tested under realistic engine conditions by EUROMOT's members. which evaluate the reliability and durability of the substitute materials/components relative to their specific design requirements. This testing needs to be undertaken by each engine manufacturer to ensure the testing reflects the demands of their application and the tolerances that are inherently in-built into each system, moreover specific test rigs need to be available.

The level of testing, and therefore the timescale required for testing, will vary depending on how closely the PFAS-free alternative match the necessary technical requirements, the types of engine and their end-uses. For example, if the component's electrical and functional properties are apparently identical, then a lower level of testing is necessary. However, substitute materials often given different characteristics, so under these circumstances more extensive testing is needed.

Sometimes substitution results in component suppliers withdrawing their products from the market and replacement by a different component (this is common with integrated components) in which case EUROMOT's members may need to redesign circuits and this could affect engine emissions and so recertification will be required.

EUROMOT members will undertake some or all of the following, with the exact testing depending on the change being undertaken:

- Construction of engines using the PFAS-free replacement components and bench testing to determine reliability with testing of long-term reliability are an important factor for many components. Testing can include the following:
- Mechanical properties specific to the end application, such as gravel bombardment testing for exhaust system components, flow velocity
- Vibration testing / Vibration resonant sweep: a shaker test used to detect if any resonances in the component may adversely affect the device
- Humidity testing
- Thermal cycling
- Corrosion tests / Salt fog testing and
- Chemical compatibility and stress fracture testing

- Water intrusion testing/ Immersion testing
- Thermal Shock: extreme temperature swings are used to stress the assembly
- Functional testing of circuits- examined at maximum temperature voltage and duty cycle combinations and shown to be in the devices specified operational envelope
- Electromagnetic compatibility testing
- Electrostatic discharge exposure robustness testing
- Electrical field immunity testing-radiated immunity and high voltage spike
- Software testing to ensure compatibility and no errors
- Combined Environment: sensors are subjected to a combination of temperature and vibration to evaluate the component assembly for the expected life of the item, testing functionality such as pressure, differential pressure, temperature, positions, speed of sensor results and performance
- Long endurance testing on test benches
- Simulated field testing

It should be considered that due to the specific demands EUROMOT members product operate within and the long operational life the qualification and validation testing need to consider all foreseeable operational conditions to be able to assess the potential impacts of a PFAS-free solution. The combined testing requirements can be 500,000+ cumulative hours to understand if the alternative is equal to that of current PFAS materials, with individual tests taking anywhere from 15 hours to two months per test. If electronic software change is also required with appropriate validation, experience has shown that this alone can take anywhere from 25 to 60 weeks. The need for specific tests according to the component type could significantly impact the substitution timeframe. The timeframes for each of these tests cannot be further accelerated as some attributes are non-linear, such as long-term reliability or durability.

Assembly structures have to be rebuilt; new assembly concepts have to be created. Training of the service departments will be necessary.

Due to the time requirements and limitations of some test equipment the testing of these parameters could be a bottle neck for qualification, especially when the availability of suitable trained engineers is considered.

Changing to PFAS-free materials or components in some instances will most likely require a change in the engine design, not just replacement of the item on a one-to-one basis with the exact same technical characteristics. This is deemed likely to be the case for components such as bearings/bushes, manifolds, gaskets, fuel hoses, O-rings just to name a few and for components such as these the longest timeframes outlined below will be necessary to ensure that reliability is not negatively impacted. This could trigger the need for entire assembly structures be redesigned, for example, the mating material, oil film and tolerance will need to be redesigned to be compatible and this adds to the total development time.

Field trials in end-use equipment. This is important because it is not possible to reliably reproduce field conditions in laboratory testing environments. Each machine must pass an endurance run (for several weeks) and an outdoor testing (for several months) in two loops. This is essential to assess the long-term reliability and has previously identified critical technical differences in the testing of alternative bearings which would otherwise have reduced the service life of engines. Due to limited testing capacities, this cannot be done in parallel, which means that the release period for the affected product range is very long.

If new components require significant changes, for example if the replacement of the PFAS-containing part is not technically equivalent and requires the re-design of circuits due to electrical components having different technical capability or the redesign of engine to reduce the operating temperature. This will then trigger the need for approvals under the Non-Road Mobile Machinery (NRMM) Emissions Directive 1024/2012.

In addition to the testing above, certain components also have specific tests which have to be undertaken. Once such example is fuel hoses and gaskets in fuel filler caps, which require an evaporative test to fulfil the evaporation requirements in EPAIII and CARB IV and takes approximately 1 year to undertake. On other example is for marine commercial applications where new testing and type approvals may be required under the IMO SOLAS Convention and classification rules.

Timeline to develop PFAS-free alternatives

EUROMOT members have engaged extensively with their supply chain and, PFAS-free alternatives for EUROMOT applications are not available from the suppliers at this time. As such predicting a timeline for assessing the transition to a PFAS-free alternative is difficult and EUROMOT members are reliant on their supply chain to develop alternatives with suitable characteristics.

EUROMOT members are constantly developing more sustainable products and the industry is continuously researching alternatives. The timescales for the testing to be undertaken by EUROMOT members takes between five and up to eight years, with the exact time period depending on the type of component substitution, type of engine and its end-uses. Typically, components which do not affect the emission approval would take >12.5 years after PFAS-free substitutes become available, whereas those which do affect the approvals would take least >13.5 years after PFAS-free substitutes become available.

Due to the extremely large number of components and materials utilising PFAS, with more than 1900 assemblies affected in one EUROMOT members product range, a longer timeframe will be needed. This is based on the consideration that when EUROMOT members had to redesign their products between 1997-2007 to comply with the updated EU emissions regulations, the process took 7-10 years. However, the number of affected parts during this process in comparison with the number of PFAS containing parts was much lower and the development of PFAS-free alternatives will be an even more challenging and lengthy process. In combination with the capacity and resourcing issues mentioned above it is more likely that more than 13.5 years is required to integrate PFAS-free alternatives in all applications, as outlined in Table 4-1.. This is still assuming that ‘drop-in replacements’ are available for all solutions.

Table 4-1 Timeline to Test and Recertify a PFAS-free material in EUROMOT members products.

Activity	Time
Identification of parts and subcomponents	1+ years
Component validation of new material	1 year
Product validation with new material components	1 year
Assembly pre-development	2 years
Development product and process, realisation product and process, production under series process, production in start-up phase	4 years
Implementation in machinery fleet	3 years

Activity	Time
Turn inventory to purge supply chain & ensure compliance	6 months
Recertification	1-3 year
Total	**>13.5 years** once a PFAS-free component has been identified by EUROMOT members supply chain

5 ENVIRONMENTAL IMPACT, END OF LIFE AND WASTE CONSIDERATIONS

EUROMOT members are downstream users of PFAS substances and as such are not manufacturers and have limited use of PFAS during manufacturing processes, as such there are no expected emissions during the engine system manufacturing process or EUROMOT members. The PFAS used within EUROMOT members products generally are in locations with no user access and if parts are accessed for maintenance purposes all users would be wearing personal protective equipment and the risk of exposure negligible.

During the lifetime of the engine, it is possible that minimal amounts of wear of the engine components could occur, including PFAS containing components, however this would be retained in the engine oil which is handled and disposed of as per EU legal requirements. Moreover, there are studies investigating the decomposition of PFAS substances during waste incineration processes. A noticeable example is the complete thermal decomposition of PTFE at temperatures above 800°C resulting in safe incineration in municipal waste incineration facilities.[14]

All refrigerants and lubricants are run in closed loops, and are collected and appropriately disposed of at the equipment's end of life. Engines are designed to avoid the losses of such substances and no losses are expected to occur during normal operation conditions as fluid loss will lead to shut-down due to failure of the system.

EUROMOT member products have to meet specific environmental requirements, such as the EPA[15] and CARB[16] Regulations which places requirements for fuel hoses to limit evaporation to the following:

- 15g/m²d for non-road fuel lines, and
- 225g/m²d for cold weather product fuel with a high aromatic content.

As shown in Table 5-1 and Figure 25, the PFAS-free alternatives tested by DuPont not only do not match the performance of FKM which is currently in use, but in many cases also do not meet the regulatory requirements.

[14] 5 Aleksando, K., Gehrmann, H-J., Hauser, M., Matzing, H., Pigeon, D., Stapf, D., Wexler, M. (2019). Waste Incineration of Polytetraluoroethylene (PTFE) to Evaluate Potential Formation of per- and Poly-Fluorinated Alkyl Substances (PFAS) in Flue Gas. https://reader.elsevier.com/reader/sd/pii/S0045653519306435?token=C28A68B6BA19186C7EB4F1E09BCDA2C9C84A214D3983E5D75466538CB7B1B878A8DE1A4EF7A7849515099480AECD99AB&originRegion=us-east1&originCreation=20230509140l2

[15] EPAIII EPA 40CFR 1060.515 from 8th October 2008 and SAE J2996 (2013-01).

[16] CARB IV (TP-901 Adopted: 26th July 2004, amended: 18th September 2017).

Table 5-1 Fuel emission with different diaphragms materials.

Elastomer	Fuel 1 (g/m²d)	Fuel 2 (g/m²d)
FKM	2.6	1
Proprietary thermoplastic polyester elastomer polymer (ECO)	225	36
Nitrile rubber type 1	456	204
Nitrile rubber type 2	564	408

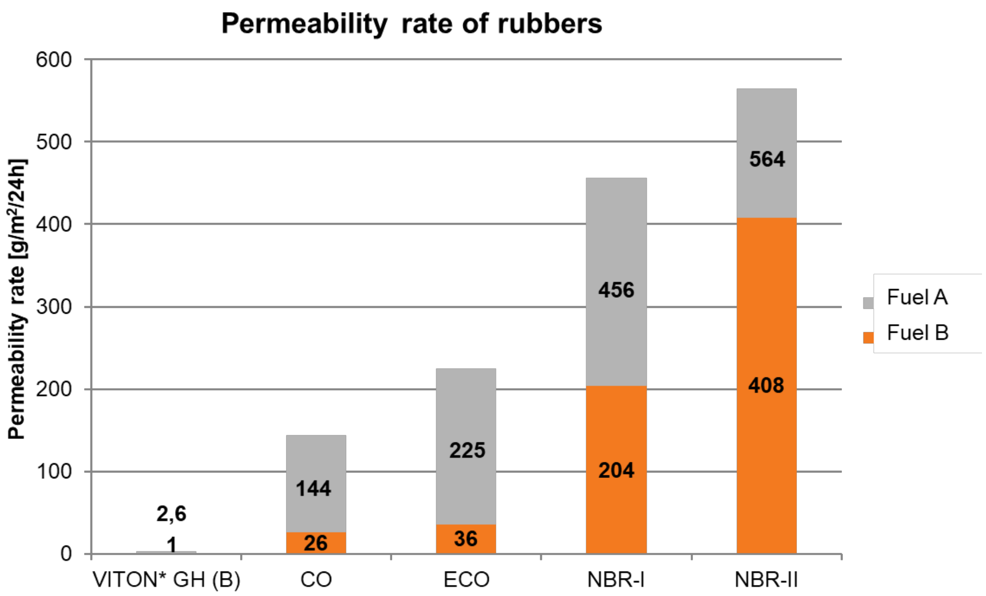


Figure 25 Permeability rate of different polymers.[17]

Due to performance differences such as the differences in permeation rates between Viton (a PFAS polymer) and PFAS-free materials shown in Figure 25, there is the concern that the use of PFAS-free alternatives, as they do not currently offer the necessary technical performance, would result in an increased failure rate of components. Such components would trigger the need for components having to be replaced sooner due to damage or component aging, causing a decreased service lifetime and increased waste. It is also expected that even with the increased service frequency that the engine system lifetime will be reduced from 20-40 years currently offered to a much shorter timeframe and causing increased waste due to the early disposal of engine systems which can weigh up to several tonnes for heavy-duty machinery.

6 PROPOSED DEROGATION UTILISED BY EUROMOT MEMBERS

Due to the critical PFAS uses within EUROMOT members equipment and the need for a suitable length of time to develop and qualify PFAS-free alternatives. EUROMOT proposes the following wording to be included in the derogation 6o, with points of alternation highlighted in bold:

[17] "Resistance of elastomers to alcohol-containing fuels" A. Nersasian, J.D. MacLachlan, E.I. du Pont de Nemours, Inc.

"Applications affecting the proper functioning related to the safety and **reliability** of **Internal Combustion Engine systems and Alternative Powertrain systems,** and affecting the safety **of humans or reliability of equipment** until 13.5 years after entry into force".

The updated wording is suggested to include:

- The addition of **reliability of equipment** to ensure operation of the equipment without early failures. Due to the criticality of EUROMOT applications premature failure would cause severe repercussions on operation activities and would result in an increase in waste produced.
- Alter the scope from 'transport vehicles' to **internal combustion engines systems** and **alternative powertrain systems,** due to the similarity in the technical requirements. The proposed wording would clearly communicate that combustion, electric and hybrid systems which are the primary means of moving a system is permitted under the derogation. Given EUROMOT members reliance on its supply chains development, this would also ensure that essential components associated to the **engine system**, such as piping, tubing, fuel distribution and internal fuel storage, electronics, aftertreatments are also covered ensuring reliability of the system against disastrous failures.
- Original wording included 'affecting safety of operators, passengers or goods'. The wording original phrasing of the derogation would limit safety considerations to specialised personnel and vehicles passengers. EUROMOT members feel the need to expand safety concerns to the general public and to all engine applications beyond vehicles to include operators, technicians, passengers, or people in the vicinity of the operations.

6.1 Batteries

It is also worthwhile highlighting that batteries play an important role for EUROMOT members as they are integrated into EUROMOT products, provide auxiliary power sources, and have a key role in the aim to achieve electrification and net zero in a number of industries.

Batteries are present in EUROMOT products in the following ways:

- NRMM (portable batteries, industrial batteries, which includes battery packages consisting of battery cell, electronic components, cables, housing, displays, etc.), marine drivelines and stationary energy storage systems, and
- Some EUROMOT members design and manufacture battery packages for various applications, using the battery cells that are available on the market.

EUROMOT members are producers of battery packages but not producers of battery cells and as such support the submissions by EUROBAT and RECHARGE which outline the technical details on the essential use of PFAS substances in battery applications. However, EUROMOT members would like to take this opportunity to highlight the need for additional time beyond the request of the battery industry to be able to implement PFAS-free batteries in their equipment. This is due to the need to undertake systems level qualification which are estimated to take an additional 2 to 3 years to redesign and test the battery packs. This time would be used to undertake qualification such as water repellence and temperature of operation to reflect the operational range of EUROMOT members (-20°C to 60°C).

Battery packages

EUROMOT members would like to take this opportunity to highlight an additional PFAS use which may not as yet be outlined in battery producer responses and offer the following technical information. Some

EUROMOT members design and manufacture battery packaging which utilise battery cells already placed on the market but allow their use in a wider variety of end uses.

The battery packaging utilises the fluoropolymers in the following ways:

- PTFE or PVDF as binding agents (at <1 wt% of the cell). They serve exclusively to bind the electrochemically active material to the current-collecting substrate and thus influence product properties such as power, service life (hundreds of cycles) and safety (chemical stability over lifetime, stability up to 5V, thermal stability beyond 100°C).

- PTFE is also used to seal the battery cell, due to its ability to provide excellent moisture ingress, high chemical, and thermal stability. Due to these technical parameters it is able to prevent short circuits, cell opening and its performance at elevated temperatures >100°C.

- Electrolyte additives, such as FEC, to guarantee the stability of passivation layers and therefore a reduced capacity loss and increased service life of the cell.

There are currently no alternative substances available that meets the required properties:
- Chemically stable with all components of the electrolyte,
- Mechanical stability against vibration or other parameters,
- Heat resistance up to and beyond 100°C,
- High electrochemical stability in a potential window up to 5 V, and
- Water repellence.

The current Battery Directive (2006/66/EC) is due to be replaced shortly by the Battery Regulation with its entry into force in August 2023 which requires producers to take back batteries. All portable batteries have to be returned to any collection point. These can be supermarkets, recycling centres, or other such centres. Collectors are obliged to take back batteries regardless of the manufacturer and pass them on to recycling specialists. For other electronic devices containing batteries there are municipality collection schemes that dispose of the electric products according to local regulation. Therefore, it is expected that batteries integrated in the devices manufactured by EUROMOT members will be collected and disposed of appropriately preventing environmental release.

6.2 Spares, Repairs and Remanufacturing

It is important to note that PFAS are not only needed to manufacture new engine systems but also for servicing and maintaining existing products already placed on the market. EUROMOT devices generally have a long service life with devices often having lifespans of 10-15 years, and certain EUROMOT devices having a considerably long lifespan of up to 40 years. It is likely that in many applications there will not be a drop-in replacement for the PFAS on a 1:1 basis due to different properties such as chemical inertness, tightness, and functionality. Systems will therefore need to be redesigned to permit the use of PFAS-free alternatives. Without the general consideration to permit the use of PFAS in these applications this will cause the premature end-of-life and scrap of engine systems which otherwise could be serviced, repaired, and maintained with PFAS-containing parts and be kept in service. The restriction as proposed would also affect already produced products subjected to remanufacturing and have an impact on the second hand machinery market.

Service, maintenance, and repairs are crucial for the success of the European Green Deal when it comes to better resource efficiency and therefore it is important that this is reflected in the derogation request.

6.3 Derogation Extension Process

As is outlined in this report EUROMOT members are reliant upon their suppliers in many cases identifying PFAS-free alternatives before they are then able to undertake systems level qualifications. Due to the early stages of their development there is a significant degree of uncertainty in estimating an accurate timeline and additional time may be required. The timeline extension could be triggered by one or more of the following assumptions not proving to be valid, or there being unforeseen challenges yet to be identified.

- The necessary technical attributes will be identified in the first round of testing and will not require tests to be recompleted or for the testing to move back a stage as an untenable characteristic has been identified, and
- That the necessary resources are available to complete the testing. Considering that the elimination or substitution of a whole class of chemicals, like PFAS, is unprecedented this has the potential to add a significant amount of time to identify and implement each alternative as EUROMOT members will be facing the need for the concurrent qualification of many thousands of parts.

Although EUROMOT members and their supply chain are actively engaged in gathering information on the uses of PFAS within their products, as yet not all have been identified. In part this is due to the challenges in their identification as many PFAS used in mixtures have not been classified as hazardous per the Globally Harmonised System for classification and labelling. In addition, they have not been listed as SVHC or included on the Candidate List of SVHC for Authorisation. Therefore, many PFAS are not shown on material data sheets even though the substance is present. Moreover, when PFAS are used as articles or articles in complex objects, the parts suppliers are currently under no regulatory obligation to highlight the presence of PFAS.

Due to these factors it is essential that a formal process for requesting permitted derogations to be extended beyond the originally agreed time period is permitted and published.

Appendix A

A.1 PFAS substances

List of substances and uses identified by EUROMOT members.

Table 6-1 EUROMOT member specific PFAS uses.

Chemical	Use(s)
1-Butanesulfonic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, potassium salt (1:1)	Connector assemblies in electric vehicle cars
1-Hexene, 3,3,4,4,5,5,6,6,6-nonafluoro-, polymer with ethene and tetrafluoroethene	Drive trains Power train control and energy systems Vehicle equipment Convertor unit Fuel sensor units
1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene	Acoustics Filtration Hoses Hydraulics and pneumatics Interior and exterior plastics O-rings/ gaskets Plugs Power control and energy systems Powertrain components Seals Seats Sensors Present in fluorine rubber (FKM) and Viton
1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene	Temperature sensors Valves Vapour separator assemblies Cables Switches Socket charge assemblies
4,4'-(2,2,2-Trifluoro-1-(trifluoromethyl)ethylidene)diphenol	Solenoid valves Exhaust manifolds Gaskets
Ammonium-pentadecafluorooctanoate	Panel assemblies Spark units
Ethene, tetrafluoro-, homopolymer	Belts Cable insulation Compressors Filters Fuses Gaskets Heaters Hoses Hydraulics and pneumatics Interior and exterior plastics Lubricants

Chemical	Use(s)
	Metal parts Power control and energy systems Power systems Powertrain components Pumps Seals/O-rings Sensors Solenoids Switches Tyres Valves Used in polytetrafluoroethylene (PTFE) and silicone rubber vinyl methyl silicone (VMQ) coatings
Tetrafluoroethylene propylene	Seals
FKM	Analytical safety gloves and other components Bearings Bushes Clutch disks Diaphragms Hoses O-rings/gaskets (fuel contact) Sealant compounds Seals (fuel contact) Manifolds Vents
Fluoropolymers (FKM, PTFE, PVDF, etc.)	Proton exchange membranes
Fluorpolymer and perfluoropolymers	O-rings
Fluorovinylmethylsiloxane rubber / fluorosilicon rubber	Acoustics Filtration Hydraulics and pneumatics Interior and exterior plastics O-rings/ gaskets Powertrain components Powertrain control and energy systems Seats Valve components
Proprietary fluorocarbon rubber	Seals between oil cooler and cooling fluids
Hydrofluorocarbons & hydrofluoroolefins	Heat transfer
Octanoic acid, 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluoro-x	Panel assemblies Gauge components Oil level sensors
Perfluoropolyether	Display assemblies Electric Drive Unit assemblies Plug Cap Hydraulics and pneumatics Interior and exterior plastics Power control and energy systems Powertrain components Vehicle equipment

Chemical	Use(s)
Perfluoroalkoxy alkanes	Acoustics Filtration systems High voltage cables Hydraulics and pneumatics Interior and exterior plastics Metals Power control and energy systems Seats
PFAS containing fluids	Coolants Lubricants
Phenol, 4,4'-[2,2,2-trifluoro-1-(trifluoromethyl)ethylidene]bis-	Engine assemblies Hoses Seals Used in Viton, FKM and black fluorocarbon rubber material
Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], .alpha.-(1,1,2,2,2-pentafluoroethyl)-.omega.-[tetrafluoro(trifluoromethyl)ethoxy]-	Electronic assemblies Greases PCBs Sensors
Propane, 1,1,1,2,2,3,3-heptafluoro-3-((trifluoroethenyl)oxy)-, polymer	Vapour separator assemblies Fuel hoses
Propanoyl fluoride, 2,3,3,3-tetrafluoro-2	Electronic assemblies Hydraulics and pneumatics Interior/ exterior plastics PCBs Power control and energy systems Sensors General vehicle equipment
Propanoyl fluoride, 2,3,3,3-tetrafluoro-2-(1,1,2,3,3,3-hexafluoro-2-(heptafluoropropoxy)propoxy)-, polymer with trifluoro(trifluoromethyl)oxirane, reaction products with 3-(ethenyldimethylsilyl)-N-methylbenzenamine	Display assemblies ECU assemblies Plug caps
Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene	Oil sensors Solenoid valves Exhaust manifolds Gaskets Gauge components Oil level sensors Free lock height adjusters
PTFE	Analytical lab components Batteries – electrolyte binder, electrolyte, separator Bearings Bushes Coatings Diesel exhaust fluid Fuel filters Gaskets High voltage cables

Chemical	Use(s)
	Hoses (fuel contact) Housings Injectors used in high pressure cleaning Lubricants Plugs Power control and energy system Powertrain components Seals/ O-rings (fuel contact) Tribo-optimised plastics (Gaskets, fan wheels, injectors, sliding pieces)
PVDF/PVF	Batteries – electrolyte binder, electrolyte, separator Cable insulation Hoses Valve components
R-1234yf	Refrigerant in air conditioning compressors
PFAS based refrigerants	Refrigerant

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