



ExxonMobil Petroleum & Chemical BV (EMPC) Comments on Annex XV restriction report on per- and polyfluoroalkyl substances (PFAS)

**Fluoropolymer use in upstream,
refining, and petrochemical
manufacturing.**

21 September 2023

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Fluoropolymer use in upstream, refining, and petrochemical manufacturing



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Acronyms and Abbreviations

ECHA	European Chemical Agency
EEA	European Economic Area
EiF	Entry into Force
EPDM	Ethylene Propylene Diene M-class rubber
ESIG/ESVOC	European Solvents Industry Organization for substances of low volatility
ECTFE copolymer	Ethylenechlorotrifluoroethylene
ETFE copolymer	poly(ethene-co-tetrafluoroethene)
FEP	Fluorinatedethylenepropylene
FKM	fluoroelastomer
FFKM	Perfluoroelastomer
FLSs	Flurosilicones or Fluorosiloxanes
FP	Fluro Polymer
HDPE	High Density Polyethylene
HNBR	Hydrogenated Nitrile Butadiene Rubber
HPHT	High Pressure – High Temperature
LDPE	Low Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
mLLDPE	micro–Linear Low Density Polyethylene
NFPA	National Fire Protection Association
NBR	Nitrile butadiene rubber
OECD	Organisation for Economic Co-operation and Development
OPC	Open Public Consultation
PDMS	Polydimethylsiloxane
PE	Polyethylene
PEBHF	Phosphate-ester based hydraulic fluids
PEEK	Polyether ether ketone
PFA	Perfluoroalkoxy alkane
PFAS	Per- and Polyfluoroalkyl Substance
PFPE	Perfluoropolyether
PLC	Polymer of Low Concern
PPE	Personal Protective Equipment
PPS	Polyphenylene sulphide
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidene fluoride or polyvinylidene difluoride
R&D	Research & Development
SEA	Socioeconomic Assessment
SpERCs	Specific Environment release categories
VMQ	VMQ (Silicones) are a group of elastomeric materials made from silicone, oxygen, hydrogen, and carbon

1. EXECUTIVE SUMMARY

This response is submitted on behalf of ExxonMobil Petroleum & Chemical BV (“EMPC”). For the purpose of this submission, EMPC is acting in its own name and in name and on behalf of the other affiliates potentially affected by the proposed REACH restriction (hereafter referred to as “ExxonMobil”). EMPC is a subsidiary of Exxon Mobil Corporation and part of the ExxonMobil group of companies (“ExxonMobil Group”).

Exxon Mobil Corporation manages an industry-leading portfolio of resources, and is one of the largest integrated fuels, lubricants and chemical companies in the world. Its business encompasses but is not limited to all aspects of the oil and gas industry, including Upstream, Products Solutions (including downstream and chemicals), and Low Carbon Solutions.

ExxonMobil’s operations often take place under extreme conditions, such as very high temperatures and pressures, mechanical fatigue and stress, as well as in the presence of corrosive chemicals. It is therefore imperative that the equipment used withstands these harsh conditions over long periods, which can reach 30 years in some cases (e.g., offshore drilling and transportation).

Fluoropolymers are critical materials used in equipment and infrastructure necessary for the safe and reliable operation in oil and gas value chain sites. They exhibit a unique combination of temperature and chemical resistance, along with mechanical durability, which makes them ideal for use under a wide range of environmental conditions and contact with corrosive chemicals on a constant basis.

Common applications of fluoropolymers as components in equipment used in oil and gas operations are:

- sealings (O-rings, gaskets, seals) in pipelines, pumps, and valves,
- linings and sheaths in pipelines transporting hydrocarbons or corrosive substances,
- flexible pipe and risers,
- filters and sealings,
- coatings on surfaces of tanks, offshore structures, and other equipment,
- other essential equipment such as wire and cable housing valves, bearings, seals around critical monitoring devices (such as pressure transducers, temperature thermocouples, emissions monitoring probes etc) and laboratory equipment.

Any material used in equipment operating under harsh conditions of thermal, chemical and mechanical stress must be able to maintain its shape and function throughout the equipment’s or component’s long service life. In addition, it must be able to provide the performance necessary to meet the safety and reliability requirements as set by industry and regulatory standards. The oil and gas industry uses an extensive set of safety and performance standards in their operations. The American Petroleum Institute (API) and the International Organization for Standardization (ISO) standards are widely used and meeting the requirements often needs the use of fluoropolymer components, such as seals. A number of these industry standards have also been integrated into national legislation in the European Economic Area (EEA).

Materials that have been considered as potential alternatives include plastics such as polyolefins and polyamide, rubbers, such as hydrogenated butadiene nitrile and ethylene propylene diene monomer, polyether ether ketone, polyphenylene sulphide, metal alloys, such as titanium and nickel, silicone rubbers, among other materials. None of these alternatives can display the combination of thermal and chemical resistance and overall durability of fluoropolymers. Therefore, they are not suitable for the highly demanding applications where fluoropolymer components and coatings are used in the oil and gas industry.

Furthermore, it should be noted that substitution of any single component in a piece of equipment can be a long process, even if an alternative is available, as the alternative component and the process it

is used in must be validated at laboratory and pilot scale before full scale production commences. Such processes can take several years and depend on the complexity of the process and the intensity of the operating conditions.

The PFAS restriction proposal proposes a derogation for the use of fluoropolymers in petroleum and mining industry until 13.5 years after Entry into Force (EiF). This proposed derogation only covers part of the exploration and production (i.e., upstream) segments, while the applications in transportation, refining and petrochemical operations appear not to be fully included in the scope of a derogation. In addition, even though the dossier submitters propose a long derogation period of 13.5 years as the longest available, it is very likely that suitable alternatives will **not** be available for all uses and applications after the end of this period given the very strict specifications the oil and gas industry has to comply with in all their processes.

If the restriction text remains as proposed, it is very likely that the whole oil and gas industry will be adversely affected, as they will not have access to necessary equipment or spare parts to perform their operations safely and reliably. If they were to use materials with different properties and lower resistances to temperature, chemicals or mechanical stress, it could result in more frequent need for repair or replacement. In some cases, e.g., flexible pipe used in offshore installations upstream, repair may not even be an option, so it would be essential that the alternative material performs for the whole of its service life. Interruption in operations, safety critical systems or business critical systems would lead to business continuity issues or potentially process safety issues. Therefore, if no additional derogation is granted, the whole oil and gas, petrochemical and energy supply chains in the EEA could be disrupted.

Industry is essential for modern life. It produces electricity to power homes and workplaces. It provides fuels and lubricants for transportation, cement and steel for construction, and the building blocks for products we use every day, ranging from medical supplies to electronics to food packaging.

The oil and gas industry provides many chemicals and products that are essential for daily life, and the industry has been supplying the EEA and the rest of the world with energy products, lubricants, plastics and specialty chemicals continuously for decades. As industry evolved, fluoropolymers have become an essential part of the oil and gas industry supply chain, enabling safe and reliable operations in all refineries, petrochemical plants and exploration sites. Their continued use is thus critical to maintain this steady supply of diverse and essential petroleum and chemical products and services. Their future use in a lower carbon industry will be required to provide customers with a range of options to tackle the challenge of reducing emissions in their operations.

Therefore, as the existing derogation does not cover uses adequately in the entire oil and gas industry, ExxonMobil would request, as per the details given in the Socio-Economic Assessment section of this report, that a Continued Use Scenario be adopted, with a time-unlimited derogation encompassing the use of fluoropolymers in the whole oil and gas industry as defined in this report. It can be added to the restriction proposal as follows:

Use of fluoropolymers in equipment and infrastructure of the entire oil and gas industry including but not limited to upstream, transport, refining and petrochemical operations.

2. BACKGROUND INFORMATION

Exxon Mobil Corporation manages an industry-leading portfolio of resources, and is one of the largest integrated fuels, lubricants and chemical companies in the world. The ExxonMobil Group evolved an operating model and global organization to better leverage the scale of its increasingly integrated company and global brands. There are three core businesses with operations around the world¹:

- Upstream business - Focused on strengthening energy security by expanding low-cost-of-supply, high-return oil and natural gas operations.
- Product Solutions business - Integrating downstream and chemicals operations to develop lower emission fuels and innovative products needed by modern society.
- Low Carbon Solutions Business - Helping lower emissions by providing solutions to industrial and commercial customers in growing markets for carbon capture and storage, hydrogen and biofuels.

ExxonMobil's history of operating in Europe is more than a century long and Europe has played an important role in some of the key milestones that marked their development into a manufacturer of the products that drive modern transportation, power cities, lubricate industry and provide petrochemical building blocks that lead to thousands of consumer goods.

The ExxonMobil Group's Corporate brands include:

- Esso: Customers around the world have come to respect and rely on Esso-branded fuels, services and lubricants for their personal and business needs.
- Exxon: Customers have also come to respect and rely on Exxon-branded fuels, services and lubricants for their personal and business needs.
- Mobil: Marketed around the world, Mobil is known for performance and innovation. Mobil is recognised for its advanced technology in fuels, lubricants and services; and
- ExxonMobil Chemical: There is a broad portfolio of petrochemical product brand and service solutions. These products play a key role in enabling the manufacture of affordable, sustainable and safe products that are helping meet the growing demands of an increasing global population.

With specific regard to chemicals and specialties, it has manufacturing capacity in every major region of the world, serving large and growing markets. More than 90 percent of the company's chemical capacity is integrated with refineries or natural gas processing plants²:

- The portfolio includes product and services (branched alcohols, branched higher olefins, butyl, EPDM rubber, linear alpha olefins, neo acids, plasticisers, polyethylene, polymer modifiers, polyolefin plastomers and elastomers, polypropylene, solvents & fluids, synthetic base stocks, tackifiers, transformer oils and thermoset systems);
- The industrial sectors supplied include: adhesives and sealants, agriculture, automotive, building and construction, compounding, consumer products, healthcare & medical, hygiene and personal care, industrial applications, energy, packaging, synthetic base stocks.

This document is being submitted by ExxonMobil in response to the public consultation on the universal PFAS restriction proposal, which was initiated by ECHA and runs until 25 September 2023.

The ExxonMobil Group does not manufacture per- and polyfluoroalkyl substances (PFAS). As part of their response, ExxonMobil wants to present relevant data on the uses and applications of certain PFAS and respond to ECHA's public consultation questions, which are applied in a number of

¹ <https://corporate.exxonmobil.com/who-we-are/our-global-organization#Aglobalcompany>

² <https://www.exxonmobilchemical.com/en/>

products in industry sectors and applications including, but not limited to, the uses identified in this report.

ExxonMobil will be submitting reports covering the following uses:

- Fluoropolymer is used in upstream, refining, and petrochemical manufacturing.
- Aviation hydraulic fluid additive
- Additives in lubricants
- Processing additive for polyethylene
- Clean agents in fire suppression systems

Please note that the information able to be submitted at this juncture is incomplete. The scope and potential impact of the proposed restriction is unprecedented and open-ended. Many thousands of substances would be subject to the restriction, and few of these substances are identified in the proposal on an individual basis. Accordingly, more time would be needed to do a more comprehensive and complete assessment. Due to the absence of identification of the individual substances that are in scope of the proposed restriction, the current assessment has been limited to those substances that are known to be used by ExxonMobil and are within the proposed restriction's scope. ExxonMobil reserves their rights in this context.

The information provided will describe in detail the sectors and sub-uses involved and the potential impact of the current restriction proposal, demonstrating the necessity of the use of certain PFAS in these applications, the potential for substitution, and the importance of the use, and continued use, with specific regard to the EEA.

3. OVERVIEW OF USE

3.1 Sectors and sub-uses

Exxon Mobil Corporation is one of the largest integrated fuels, lubricants and chemicals companies globally. Its business encompasses all aspects of the oil and gas industry, including Upstream, Products Solutions (including downstream and chemicals), and Low Carbon Solutions. The value chain of ExxonMobil businesses extends to end users of products and services, which can be found across all industry sectors in the EEA, including, but not limited to, automotive and aerospace, building and construction, chemical processing, including agrochemicals and pharmaceuticals, packaging.

These businesses are further defined as:

- Upstream operations, which include exploration production and transport of the crude oil and natural gas until the storage depots in refineries across the globe.
- Refining operations, including several locations in the EEA, which then feed into downstream processing units operated by both ExxonMobil and its customers. Output from these include fuel and lubricant blends and feedstock for petrochemical processing. Crude oil refineries produce a wide range of products, including transportation and industrial fuels, chemical feedstock and other, specialty products, such as lubricants, coke, waxes and solvents, and bitumen.
- Petrochemical processing operations, which process specific streams from the refineries into specialised products for use in synthesis and other applications. ExxonMobil is running hundreds of these processes in their plants. It should be noted that some of these processes are integrated into the refining process for the feedstock for greater efficiency and lower costs.
- Low Carbon Solutions, an emerging business, leverages the scope and expertise of ExxonMobil and is focused on carbon capture and storage, hydrogen, and low-emission fuels like second-generation biofuels. Developing low carbon solutions is one of the ways that ExxonMobil can make a difference in the energy transition in the EEA. As a company, ExxonMobil plans to:
 - focus on reducing emissions in its operations through avoidance and improvement of energy efficiencies.
 - provide low carbon products to help customers reduce their emissions.
 - develop and deploy scalable technologies, such as those described above, to help decarbonise sectors with the highest emission potentials, such as manufacturing, transportation and power generation; and
 - proactively engage on climate-related policies.

3.1.1 *Overview of the use of fluoropolymers in upstream, refining, and petrochemical manufacturing*

ExxonMobil's upstream, refining and petrochemical manufacturing processes rely extensively on the use of fluoropolymer components, linings and coatings in the infrastructure and the equipment used in their sites. Fluoropolymer components are used in equipment for exploration and production in complex wellhead and marine based pipeline applications, and in the manufacturing (refining, lubricants, petrochemical, etc.) stage predominantly for sealing and lining applications. The fluoropolymers are already part of the equipment when purchased, but it is possible that small repair or coating work may take place on site. Such manufacturing processes also cover the emerging technologies required to support industry decarbonisation. This equipment is essential for ExxonMobil's processes which must be carried out under harsh conditions.

- **High temperatures:** many processes are carried out at temperatures exceeding 200 °C for extended periods of time. Similarly, equipment in oil and gas exploration and production sites must be able to withstand elevated temperatures over extensive periods of time.

- **Corrosive chemicals:** many manufacturing processes often require very aggressive (mainly corrosive) chemicals, such as sulphuric acid. In addition, the equipment is continuously storing or transferring petroleum products, which can contribute to chemical corrosion and physicochemical erosion of said equipment.
- **High pressures:** reaction and storage vessels at refineries need to operate at high pressure, along with the high temperatures and highly corrosive chemicals. Furthermore, equipment in oil and gas exploration or production wells also need to operate at extreme pressures. Some wells are drilled at great depths at the sea bottom, and offshore rigs have a rated drilling depth of approximately 12 km (35,000 ft) below sea surface, with the sea bottom often being as deep as 3.6 km (12,000 ft)³. The pressure at such depths can be as high as 400 atmospheres (1 atmosphere per 30 ft).
- **Vacuum:** some equipment and processes need to maintain a very low pressure or a vacuum.

Furthermore, petroleum and petrochemical products need to comply with certain purity and performance requirements by customers and end users, and contamination from equipment or processing aids must be avoided. International standards lay down requirements for specific properties of materials that must be met. Fluoropolymers are chemically inert and do not affect the composition or purity of the product, as they do not react with or contaminate the product.

It must be noted that most manufacturing processes in this sector are run continuously, with only periodic shutdowns for maintenance (typically every 5 years). As a result, they need to maintain the extreme operating conditions, such as high temperature, high pressure, or corrosive agents, as long as the manufacturing unit is operational. Throughout the operation, it is also important from a safety perspective that the equipment is protected from the elements to prevent mechanical failure and unplanned product releases.

Fluoropolymers are used in, but use is not limited to, the following types of equipment:

- Sealing equipment such as gaskets, sealing rings (O-rings), rotary seals, shaft seals, flanges, pipe thread wrap and sealants, used in piping and other fluid handling equipment, such as valves and pumps. These components are essential in preventing feedstock and product releases over a broad range of harsh conditions, as mentioned above (temperature, pressure, corrosive agents).
- Pipe and reactor and storage vessel lining, which transfer or contain corrosive substances or house reactions that require high temperature and pressure.
- Equipment, such as flexible pipes / hoses used mainly in exploration, production and transportation operations. A single, flexible pipe minimises the risk of a release of substances from connections and also facilitates directional bore hole drilling and also help resolve deflected (non-straight) bore holes.
- Filters and separation media, where polymers are used in the construction of both membranes and seals for the filters.
- Other essential equipment such as wire and cable housing valves, bearings, seals around critical monitoring devices (such as pressure transducers, temperature thermocouples, emissions monitoring probes etc) and laboratory equipment.

The uses listed above are representative of the majority of fluoropolymer applications, but it is not exhaustive. **Table 3-1** highlights some of the public responses by industry and trade associations to the open public consultation (OPC), which pertain to the large number of uses relevant to ExxonMobil operations and provide additional arguments and justification for a wider derogation.

³ See: <https://www.enverus.com/blog/offshore-rigs-primer-offshore-drilling>, accessed on 23 August 2023

Table 3-1. List of industry and trade association responses to the OPC that are relevant to ExxonMobil's fluoropolymer uses.

Additional uses, including, but not limited to:	Additional information identified by:	Link to information (web page / link):
Gaskets, seals	European Sealing Association	4472 (Part 20)
Plastic pipes and fittings	TEPPFA	4591 (Part 22)
Lubricants	ATIEL	4423 (Part 17)
Semiconductors	Semi Europe GmbH	4304 (Part 13)
	European Semiconductor Industry Association	4449 (Part 18)
Clean agent Fire Suppression	Euralarm	Not yet available
Fire suppression systems	European Fire Sprinkler Network	5942 (Part 25)
Hydrogen	DWV – German hydrogen and fuel cell association	4263 (Part 12)
	Hydrogen Europe	4144 (Part 9)
Batteries	RECHARGE AISBL	3925 (Part 2)
Refining	Concawe	Not yet available
Fuels	en2x Wirtschaftsverband Fuels und Energie	4057 (Part 6)
Natural gas and oil industry including exploration and production, midstream transportation, and refining and petrochemicals	American Petroleum Institute	Not yet available
Chemical Manufacturing	CEFIC	Not yet available
	FPP4EU	Not yet available
	Verband der chemischen Industrie Landesverband Nord e.V.	4503 (Part 20)
Sealings, bearings, cable sheaths, coatings, pump inserts and membranes used in pumps.	Europump	4245 (Part 11)
FP components, semiconductors, lubricants, greases and additives in vehicles	ACEA	4276 (Part 13)
HVAC-R	Asercom	4205 (Part 10)
Gas detection equipment	Council of Gas Detection and Environmental Monitoring	4323 (Part 14)

Additional uses, including, but not limited to:	Additional information identified by:	Link to information (web page / link):
Fluoropolymers	Performance Fluoropolymer Partnership (global)	4444 (Part 18)
	Fluoropolymers Product Group	6148 (Part 31) 6150 (Part 31)
Non-road equipment (mainly construction and agriculture)	Association of Equipment Manufacturers	4451 (Part 18)
Mechanical and plant engineering	VDMA	4471 (Part 20)
	VDMA eV Construction	6391 (Part 39)
Industrial gases	European Industrial Gases Association	4532 (Part 21)
Plastics	Plastics recyclers Europe	6198 (Part 32)
	European Plastics Converters & European plastics masterbatchers and compounders	6206 (Part 33)
	PU Europe	6321 (Part 36)

In general, fluoropolymers are essential in all of ExxonMobil's processes where at least one of the following extreme conditions are present: high temperature, corrosive agents, high pressure or vacuum. The most common materials used include, but are not limited to, PTFE, PVDF, PFA, but also fluoroelastomers (FKM, FFKM). Fluoropolymers are the only materials that exhibit a combination of resistances to all these extreme conditions. They have excellent chemical/corrosion resistance, thermal stability at high temperatures, low temperature flexibility, and wear/erosion resistance. They also have good dielectric properties which means that fluoropolymer coated equipment reduces the conductivity of the metal, decreasing the chance of an accidental spark from static build-up.

3.1.2 *ExxonMobil equipment and infrastructure with fluoropolymer components*

ExxonMobil's processes use many pieces of equipment that have fluoropolymer components. This equipment comes to ExxonMobil in its final form with fluoropolymer components already added by the equipment manufacturers. The list of specific applications and associated equipment is very long and the different individual fluoropolymer components in equipment used in ExxonMobil's processes are estimated to be in the millions (estimations using available requisition data are between 1 and 5 million components) for sites in the EEA and even more across the globe. This estimate does not include new project equipment and significant maintenance activity equipment (i.e., turnaround) and as a result the total number is expected to be larger. Some examples are listed below:

- Gasket, O-rings and other seals to prevent release of substances in operations carried out under extreme temperature, pressure and corrosivity conditions across the whole oil and gas industry supply chain. Specific applications include subsea components operating at the wellhead or in systems delivering products to reception points, but they are very extensively used in refining and petrochemical operations, wherever two pieces of equipment need to be connected with certainty of an inert seal, such as tanks, piping, valves and pump shafts. While there are other materials in use for seals, fluoropolymer components are preferred where the operating conditions would cause alternative materials to degrade and physically fail.

- Pumps and piping used in processes that handle very corrosive chemicals, such as sulphuric acid and sodium hydroxide. Fluoropolymer lining protects the metal equipment from corrosion and the product from contamination. In some cases, flexible fluoropolymer hoses are used, to minimise the number of connections, as these hoses can be extruded at the required length and only have connections at the termination points. Depending on the chemical involved, lining with other plastics or use of non-lined pipes is theoretically possible, but several critical lines, e.g., sulphuric acid or bromine and chlorine handling need to use fluoropolymers.
- Lining in reaction and storage vessels, which operate at high temperature and pressure, requiring inert highly resistant linings, such as reactor components, vacuum towers, chemical towers, and vessels.
- Measuring and monitoring (sensor) instruments, e.g., for pressure, temperature, conductivity, as well as in other instruments used in refining to regulate the processes. Fluoropolymers in these instruments may be present in cables and wires, and other electrical equipment.
- Conveyor belts and rollers that transport solid products, where low friction ensures lower energy consumption.
- Low coefficient of friction bearings in rotating equipment, such as agitators.
- Electronic systems in general, in which fluoropolymers are used as wire and cable jacketing, conformal coating or venting / separation membranes and filters.

3.1.3 Introduction to case study approach

The use of fluoropolymers in the oil and gas industry supply chain is extensive and there can be hundreds of different processes that need to use millions of fluoropolymer components to prevent accidental releases, protect critical process equipment and, in general, ensure that all processes are carried out safely and reliably.

The oil and gas industry supply chain is complex, with its various processes being interconnected. Refineries are operating continuously, with the output of one line feeding several others, while there are numerous auxiliary lines transporting products and process chemicals. Downstream petrochemical processes rely on products from the refineries and also need to store and transport corrosive or highly reactive chemicals such as sulphuric acid, bromine and chlorine gas and caustic solutions.

Analysing each specific process for the importance of use of fluoropolymers is not considered practical on one hand due to the sheer number of processes and applications of fluoropolymers across the oil and gas industry supply chain, and on the other hand because several of these processes are proprietary and cannot be described in detail. As such, a high-level, global, approach is followed for the purposes of this study, where the fluoropolymer applications are assessed for the ExxonMobil set of operations.

Nevertheless, ExxonMobil considers it useful to analyse fluoropolymer use in a number of applications in their processes as case studies to illustrate the importance of continued fluoropolymer use in manufacturing processes. Three critical applications were selected, one from each of the oil and gas industry sectors, namely in upstream operations, refining, and petrochemical manufacturing. These case studies are presented in Section 7, 8 and 9 of this report.

More specifically, the selected case studies are:

1. **Upstream:** Use of fluoropolymer (PVDF) pressure sheath and sealing (PTFE, fluoroelastomers) in flexible pipes used in exploration, production, transportation and storage of crude oil and gas and for injection of fluids in reservoirs in offshore operations. All processes take place in high pressures and temperatures. All components must be able to withstand these harsh conditions and maintain their functionality throughout the lifetime of the pipe, which can be as long as 30 years.

2. **Refining:** Use of fluoropolymer linings and sealing components for transportation, processing and storage of a variety of process streams (especially those containing sulphuric acid, caustic soda and hydrocarbons) during the manufacturing of finished products (i.e., fuels and lubricants) at the temperature range from room temperature up to 300 °C (and in some cases even higher) in ExxonMobil's refining operations.
3. **Petrochemicals:** Use of PTFE-lined pipes and vessels in the transportation and storage of highly reactive process streams (i.e., sulphuric acid and bromine gas) during manufacturing of chemical products (i.e., bromo butyl rubber and MEK) at the temperature range from room temperature up to 200 °C. The processes in ExxonMobil's petrochemical plants also use other fluoropolymer components, such as seals and gaskets, lined valves, coated agitators, low pressure separators, etc., as mentioned in Section 3.1.2

3.2 Performance requirements

3.2.1 Technical feasibility criteria

Potential alternatives to fluoropolymers in upstream, refining, and petrochemical operations need to have a combination of properties, in order to be considered as viable alternatives to fluoropolymers. Fluoropolymers have a combination of excellent thermal, pressure and chemical resistances, along with low dielectric constant and low coefficient of friction, which make them ideal for the very demanding applications in refining and manufacturing. Alternative materials would be required to at least have similar durability and performance under the extreme conditions in the processes in scope.

As such, the following technical criteria are considered important when evaluating alternatives.

- **Temperature resistance:** the alternative material must be able to maintain its shape and properties over a wide range of temperatures, which include extremes, as high as 300 °C or extreme cold (minus 20 °C) temperatures. The material must not degrade, which could result in it losing its elasticity, and should not expand or contract excessively, which would impact its sealing ability at extreme temperatures. Resistance to extreme temperatures is an essential criterion for alternatives used in chemical manufacturing, where processing and transfer of substances often take place in very high up to 300 °C) or very low (below freezing) temperatures.
- **Chemical resistance:** the use of corrosive or reactive chemicals, and in some cases, highly corrosive substances, such as sulphuric acid, need to be contained. These chemicals can accelerate the corrosion of metallic pipes or vessels and tanks if there is no lining to protect them or if the lining has low resistance to chemical agents. Furthermore, sealing equipment that is not resistant to chemicals will degrade quickly and may result in release of process chemicals or products to the workplace or the environment.
- **High pressure and vacuum applications:** as explained for other properties, the equipment used in chemical processing such as sealing, lining or for other purposes, must maintain their properties and their shape over long periods and under extreme conditions. Certain processes (e.g., vacuum distillation) in the refinery need to be carried out at very high or very low pressures. In addition, production equipment is often exposed to high pressure. Sealing and other equipment must not deform or crack under such conditions.
- **Low dielectric constant:** coatings with low dielectric constant serve an important safety function by reducing the conductivity of the metal equipment, decreasing the chance of an accidental spark from static build-up. This is important, e.g., for piping, where electric charge may build up during the flow of a liquid.
- **UV resistance:** exposure of materials to UV radiation could affect their consistency and degrade them, e.g., making them brittle or less flexible. This can affect the function of sealing equipment or flexible pipes, which, in upstream, refining or petrochemical sites, are often located outdoors, exposed to sunlight. Any alternative to fluoropolymers for use in such applications must be able to withstand UV radiation throughout their expected long service life.

- **(Oil and water) Repellence properties:** non-stick properties of a material used in seals or lining ensure that the product does not adhere to the walls / lining of the equipment used in manufacture and that the equipment will be easier to clean and will not retain chemicals from previous processes. This is particularly important in equipment that is used in multiple processes with different materials, as it allows shorter downtimes, as well as lower use of detergent or other cleaning agents, energy, and water or organic solvents.
- **Water / moisture resistance:** the material must not degrade or corrode when exposed to the elements or to water (e.g., in subsea installations) to ensure continued performance or protection of the sealed equipment. This property is particularly important for subsea or underwater applications where fluoropolymers are used as cable jacketing or flexible pipes and are in constant contact with sea or fresh water on the outside and hydrocarbons on the inside.
- **Mechanical strength:** this property is particularly important for equipment used in exploration and production operations, such as flexible pipes / hoses used in the well, which are constantly exposed to mechanical stress from abrasion, bending or fatigue. The materials must retain their integrity and not form cracks or break during the equipment's service life. The utility of this is twofold, as a material failure could lead to accidental releases of substances to the environment, and it could also present safety risks.
- **Non-flammability:** processes in upstream, refining and petrochemical manufacturing handle highly flammable materials and can also be carried out in conditions that could initiate combustion. Non-flammable sealing, lining or piping materials minimise the risk of combustion and protect the highly flammable chemicals in the process.

3.2.2 *Additional information on the importance of fluoropolymers in chemical processing operations*

It is worth noting that the use of fluoropolymers in the chemical, and particularly refining and petrochemical processes, is widely recognised in the scientific and engineering literature⁴.

The high durability of fluoropolymers, combined with their high degree of flexibility, electrical properties (dielectric strength) and low friction make them a highly preferable material in the oil and gas industry. They are mainly used as linings and protective coatings for metallic equipment and piping to prevent corrosion of equipment and contamination of the petroleum products⁵. Their excellent non-stick properties, low coefficient of friction and durability compared to other materials make them the material of choice for such applications. Their water and oil repellence properties reduce deposition of organic and inorganic scale on internal equipment surfaces.

Another critical function is to minimise asphaltene deposition and precipitation in storage tanks and pipelines during oil production. They can be often used to protect metallic equipment from aggressive chemicals, mechanical abrasion, wear and tear and high-temperature and pressure environments⁶. As such, their use as sealing equipment (e.g., gaskets, O-rings) in pipe connections, pumps and valves is also quite common in the oil and gas industry.

Another application is the use of PTFE as coating material for heat exchangers, among other equipment operating at high temperatures. Its stability at high temperatures and low surface energy ensure that the equipment can operate safely and reliably, without heat losses that could reduce the effectiveness of heat exchanging equipment and even cause surface erosion and fouling.

⁴ De Leon, Al Christopher C., da Silva, Italo G. M., Pangilinan, Katrina, Chen, Qiyi, Caldon, Eugene B., and Advincula, Rigoberto. High performance polymers for oil and gas applications. United States: N. p., 2021. Web. doi:10.1016/j.reactfunctpolym.2021.104878. Available online at: <https://www.osti.gov/pages/biblio/1812268>, accessed on 22 August 2023

⁵ S. Das Ramoã, G.M. Barra, R.V. Oliveira, M.G. De Oliveira, M. Cossa, B.G. Soares, Electrical, rheological and electromagnetic interference shielding properties of thermoplastic polyurethane/carbon nanotube composites, Polym. Int. 62 (2013) 1477–1484, <https://doi.org/10.1002/pi.4446>.

⁶ E.F. Lucas, C.R.E. Mansur, L. Spinelli, Y.G.C. Queiro's, Polymer science applied to petroleum production, Pure Appl. Chem. 81 (2009) 473–494, <https://doi.org/10.1351/PAC-CON-08-07-21>.

3.2.3 Technical and regulatory requirements

The oil and gas industry is required to maintain high standards of performance and safety throughout its supply chain. Their processes often involve extreme temperatures and pressures, and handling and processing of chemicals, each of which must be addressed to protect workers, the community and the environment. To ensure optimal operations with minimum risk for human health and the environment, as well as the safety of equipment, operators in the industry need to comply with a long list of regulations and industry standards. Some of these standards only have advisory character, but several are mandatory and may even be required by the national authorities where the plant is located. In the EEA, the legislation dealing specifically with the control of on-shore major accident hazards involving dangerous substances is the local implementation of the Seveso Directives (2012/18/EU) and for offshore activities, the EU Directive of safety of off-shore oil and gas operations (2013/30/EU).

In addition, ISO standards are widely used across Europe and many of them incorporate PFAS as essential elements. The list of ISO standards below is indicative of the importance of fluoropolymers for the industry to meet high safety and reliability specifications. ISO standards do not mention PFAS explicitly but make reference to equipment containing certain fluoropolymers.

Table 3-2. Indicative list of ISO standards referring to equipment containing fluoropolymers

Standard number	Standard description
ISO 23936-1: 2022	Oil and gas industries including lower carbon energy - Non-metallic materials in contact with media related to oil and gas production – Part 1: Thermoplastics
ISO 10684: 2004	Fasteners – Hot dip galvanized coatings
ISO 1629: 2013	Rubber and latices – Nomenclature
ISO 16961: 2015	Petroleum, petrochemical and natural gas industries – Internal coating and lining of steel storage tanks
ISO 31800: 2020	Faecal sludge treatment units – Energy independent, prefabricated, community-scale, resource recovery units – Safety and performance requirements
ISO 17782: 2018	Petroleum, petrochemical and natural gas industries - Scheme for conformity assessment of manufacturers of special materials
ISO 10423: 2022	Petroleum and natural gas industries – Drilling and production equipment – Wellhead and tree equipment
ISO 13628 (15 parts)	Petroleum and natural gas industries. Design and operation of subsea production systems
ISO 10400: 2018	Petroleum and natural gas industries – Formulae and calculations for the properties of casing, tubing, drill pipe and line pipe used as casing or tubing
ISO 11960: 2020	Petroleum and natural gas industries – Steel pipes for use as casing or tubing for wells
ISO 13678: 2010	Petroleum and natural gas industries – Evaluation and testing of thread compounds for use with casing, tubing, line pipe and drill stem elements

ISO 15463: 2003	Petroleum and natural gas industries – Field inspection of new casing, tubing and plain-end drill pipe
ISO 27914: 2017	Carbon dioxide capture, transportation and geological storage – Geological storage
ISO 27916: 2019	Carbon dioxide capture, transportation and geological storage – Carbon dioxide storage using enhanced oil recovery (CO ₂ -EOR)

Eleven of the above standards have also been adopted directly by the European Committee for Standardisation as regional European Standards (EN), while several of them are mentioned in European policy measures.

ISO standards are increasingly aligned with the group of standards that the oil and gas industry supply chain must comply with. These are the standards published by the American Petroleum Institute (API). The API was established in 1919, and has developed into a key organisation that establishes, maintains and publishes standards and recommended practices for the oil and natural gas industry. There are over 800 consensus-based standards intended to enhance operational safety, environmental protection, and sustainability across the industry.

The API standards are used by companies across the globe, including the EEA, and they are also adopted as national standards or technical regulations by at least 31 governments, to optimise regulatory efficiency and mandate safe industry practices. In addition, international standards organisations, such as ISO, incorporate and reference API standards in their documents, used in the EEA and internationally.

As discussed above, fluoropolymer PFAS are essential materials to all levels of operations in the oil and gas industry, providing, among others, excellent durability to a wide range of temperatures and pressures, chemical resistance, lubricity, low coefficient of friction, and non-stick properties. As a result, they are used in various components and as linings and coatings in several manufacturing processes.

This is reflected in the API standards, with 55 of these making explicit reference to use of PFAS, including fluoropolymers, as critical safety elements in various uses (also covered in Section 3.1.1), including seals in tanks, hoses, valves, and pumps, PTFE tape to prevent releases from piping, coating of equipment such as pipes, bolts and nuts, O-rings, flanges and gaskets, lubrication, flexible pipe lining, etc.

However, it should be noted that API standards require or recommend action from the side of the industry to meet the requirements for operational safety and efficiency. This approach encourages innovation from the operators, if they can meet the standard specifications. Nevertheless, the standards can be prescriptive in some of their aspects, explicitly requiring certain materials and processes. The 55 standards mentioning PFAS are in that way supplemented by several more that mandate equipment with PFAS components, without specifically mentioning those components (or linings / coatings).

In addition, this functional interchangeability of API standards allows the use of spare and sub-parts or products to maintain the performance and safety of deployed equipment over long lifetimes. Fluoropolymer components have excellent performance in a broad range of conditions and environments, and they should be available to the industry to ensure the required safety and reliability.

A more comprehensive list of API standards referencing PFAS or PFAS-containing equipment, as in API's submission to the OPC (Comment number not known at the time of submission), can be found in Appendix 1.

In the EU, API standards with PFAS references are referenced in at least 20 national policies, regulations and guidance documents. While compliance with the standards themselves is in most cases voluntary, when they are incorporated into national policies and regulations, they become mandatory to meet regulatory requirements.

Additionally, API completed a review of fluoropolymer technology potentially used in the oil and gas sectors. A full description can be seen in Appendix 2.

Overall, it can be said that API and ISO standards highlighting the use of fluoropolymer containing components are used extensively by the European oil and gas industry supply chain in enabling the industry to meet reliability and safety requirements, which are often referenced in national policies directly.

3.3 Control of potential emissions

Fluoropolymers are used in equipment in the oil and gas industries operations in final moulded solid form, either as articles (sealings, gaskets) or as linings of piping and storage vessels. They are not present as powders or other forms that have higher potential to leak to the environment. Fluoropolymers are also non-volatile, with relatively high melting points.

The fact that fluoropolymers are stable in a broad range of extreme conditions (temperature, pressure, corrosive chemicals, mechanical stress) over very long periods of exposure and that they maintain very low vapour pressure at operating temperatures means that there are no emissions of fluoropolymers to the environment during use. In addition, they do not get abraded during constant mechanical stress, so they do not generate dust or fine particles that can be washed down the drainage system.

Fluoropolymer seals and linings typically last for decades before they need to be replaced. In upstream operations in particular, flexible pipe linings and termination seals are used throughout an installation's expected lifetime, which is typically as long as 30 years.

ExxonMobil complies with all applicable laws and regulations regarding collecting, managing and treating waste generated by their activities, and maintains waste management processes during operations, maintenance or end of life decommission equipment within dedicated projects which are designed to minimise waste generation and promote segregation, separation and recycling or segregated disposal.

3.3.1 Polymers of Low Concern and bioavailability

According to recent publications (Henry, 2018)⁷ (Korzeniowski *et al*, 2023)⁸, 96% of commercial fluoropolymers meet the OECD criteria on 'polymers of low concern' (PLC) and are not expected to pose environmental and human health concerns (or hazard). The PLC criteria relate to physicochemical properties, such as molecular weight, which determine bioavailability and warn of potential hazard. PLC criteria were developed over time within regulatory frameworks around the world as an outcome of chemical hazard assessment processes, which identified physical-chemical properties of polymers that determine polymer bioavailability and thereby report a polymer's potential hazard.

⁷ Henry, B., Carlin, J., Hammerschmidt, J., Buck, R. C., Buxton, L., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymers of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management*, 14(3), 316–334. <https://doi.org/10.1002/ieam.4035>

⁸ S. Korzeniowski and all - A Critical Review of the Application of Polymer of Low Concern Regulatory Criteria to Fluoropolymers II: Fluoroplastics and Fluoroelastomers – *Integrated Environmental assessment and Management* - <https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4646>.

4. OVERVIEW OF POTENTIAL ALTERNATIVES

4.1 Introductory Note

The assessment of potential alternatives is based on the recommendations found in 'ECHA's Guidance on Analysis of Alternatives under REACH Authorisations', published in 2021⁹.

The workflow described in the Guidance encompasses describing the functionality of a substance in the particular use, followed by an analysis of the performance of alternatives. The latter requires in-depth experience of the characteristics of such alternatives to determine the extent to which such hypothetical candidates could meet or fall short as a substitute for a currently used PFAS in a particular use.

This effort requires technical expertise to review the status of readiness for the suitability/unsuitability of potential alternative substances. Particular attention is paid to the research efforts in the past years. A literature search on further alternatives based on publicly available information is also being carried out. The analysis has been carried out in a scientifically sound manner and encompasses the following key assessed dimension:

- Description of the fluoropolymer functionality in the particular use and the technical feasibility criteria;
- Efforts made to identify alternative, including own R&D efforts, if any, and other publicly available information;
- Identification and shortlisted alternatives;
- Assessment of shortlisted alternatives, which includes: availability, safety considerations as well as technical and economic feasibility of the assessed alternative.

4.2 Assessment of alternatives

4.2.1 Overview of alternatives

The broad range of fluoropolymer applications in ExxonMobil's operations means that it is impossible that a single alternative will be identified for all uses. Each use has different performance and material requirements, so different alternatives need to be evaluated for each one. The list in Table 4-1 is not exhaustive and is mostly based on information that is publicly available. Please note that the alternatives listed in Table 4-1 does not mean that they have been demonstrated to have the necessary technical feasibility.

⁹ [How to apply for authorisation_v1_corrected \(europa.eu\)](https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021G0001)

Table 4-1. Non-exhaustive list of potential alternatives to fluoropolymers in select applications

Alternative material	Relevant applications	Availability	Technical feasibility	Safety	Comments
Polyolefins (Ultra-high molecular weight PE is considered as alternative where temperatures are not as high. Polypropylene)	Pipe and vessel lining Cable jacketing	Commonly available materials in large volumes.	Good flexibility and chemical resistance Low melting point, poor temperature resistance Corrosion resistance drops at higher temperatures	Low hazard from polymer	Not technically feasible for use in the relevant applications in upstream, transport, refining and petrochemical processes, Not suitable for the high pressures and temperatures in upstream operations in particular.
Polyamides	Pipe and vessel lining Cable jacketing	Commonly available materials	Good flexibility and chemical resistance Low melting point, poor temperature resistance Corrosion resistance drops at higher temperatures	Low hazard from polymer	Not technically feasible for use in the relevant applications in upstream, transport, refining and petrochemical processes, Not suitable for the high pressures and temperatures in upstream operations in particular.
Ethylene propylene diene monomer (EPDM) Hydrogenated nitrile rubber (HNBR)	Seals and gaskets Pumps and valves Cable jacketing	Commonly available materials	Lower chemical and temperature resistance than fluoropolymers.	Low hazard from polymer	Not suitable for the uses in upstream, transport, refining and petrochemical processes.
Silicone rubbers	Pipe and vessel lining Seals and gaskets	Commonly available materials	Good temperature resistance (sometimes as high as 300°C) Low resistance to certain reactive and corrosive chemicals	Low hazard from material Some siloxanes considered for regulatory action in EU	Potentially suitable for some less demanding applications, but overall, not technically feasible for lines for corrosive chemicals
Polyether ether ketone, polyphenylene sulphide	Pipe and vessel lining Seals and gaskets Pumps and valves		Lower temperature resistance. Lower chemical / corrosion resistance. Lower flexibility		Not suitable for the uses in refining and petrochemical processes.

Alternative material	Relevant applications	Availability	Technical feasibility	Safety	Comments
"Exotic metal linings" Corrosion resistant alloys, such as zircon and titanium ¹⁰ .	Pipe and vessel lining	Relying on supply of rare raw materials. More expensive than fluoropolymers	Good temperature resistances Lower corrosion resistance and durability in general. Risk of cross-contamination if handling different fluids		Potentially suitable for some applications, particularly for dedicated lines, but may lead to contamination in mixed lines. Limited availability of raw materials is also a restricting factor.
Other alloys, e.g., Nickel or copper alloys (Lead was used as pipe lining in the past, but was replaced by fluoropolymers)	Seals and gaskets (pipe lining)				Nickel alloys, such as Monel and Hastelloy are only suitable for use to transport dry bromine but fail when the moisture content is high.
Glass lining	Pipe and vessel lining		Good temperature resistance Difficult to process and cut to fit on site. Brittle and easy to crack		Not technically feasible for upstream or refining uses as lining.
PVC	Pipe and vessel lining Cable jacketing		Good chemical and temperature resistance, but not as high as fluoropolymers and for the conditions required in oil and gas processes.		Not suitable for the uses in refining and petrochemical processes.

Sources:

Industry responses to the Open Public Consultation

<https://www.crp.co.uk/wp-content/uploads/2020/06/Guide-to-the-Selection-of-Corrosion-Resisting-Non-Metallics.pdf>

¹⁰ See: <https://www.crp.co.uk/wp-content/uploads/2020/06/Guide-to-the-Selection-of-Corrosion-Resisting-Alloys.pdf>

4.2.2 Technical feasibility of alternatives

Many of the alternative materials listed in Table 4-1 are in use by the industry. ExxonMobil already uses seals and gaskets made of non-fluoropolymer materials in many of their refinery lines. However, these materials are used in applications where the resistance and performance requirements are different.

Fluoropolymers have the unique combination of resistance to extreme temperature and pressure, and to most chemicals, including highly corrosive and reactive materials, such as sulphuric acid, bromine or chlorine gas, nitric acid, hydrocarbons and other petroleum products. Therefore, they are required over other materials in applications where combination of these properties are needed. It is important to note that fluoropolymers are in general more expensive than alternative materials. As such, they are typically the preferred option, based on safety and performance criteria.

Of the known alternatives, very few have the temperature tolerance exhibited by fluoropolymers (in particular PTFE and PFA)¹¹. These are silicon rubber, partially stabilised zirconia, and other metallic alloys, mainly used in sealing and lining applications.

However, most of these potential alternatives do not have the extensive chemical resistance displayed by fluoropolymers and are thus less suitable for use in piping, storage tanks or reaction vessels that constantly handle highly reactive or corrosive chemicals. Some specific issues on the technical feasibility of specific alternative materials, as discussed in other responses to the public consultation and based on ExxonMobil's knowledge are listed below:

- Silicone rubbers are often referred to as a material with very good resistance to a broad range of temperatures (as high as 300 °C), comparable to PTFE and FPA. However, they exhibit low resistance to some very reactive and corrosive chemicals, such as ammonia, sulphuric acid, sodium hydroxide, and bromine¹². Silicone rubbers may be used as pipe linings or sealing equipment in refining and petrochemical processing.
- Polyether ether ketone (PEEK) and polyphenylene sulphide (PPS) can be used in valves and pumps but are not flexible in the manner, nor stable at higher temperatures and do not have the same level of resistance to chemicals as fluoropolymers.
- "Exotic metal" linings have been proposed for use in piping instead of PTFE and FPA linings. They have good temperature resistances, but in general lower corrosion resistance and durability, which can lead to degradation and contamination of the product transported through the pipes. In addition, they have been reported to work better if they are used in dedicated lines, but there may be cross-contamination risk if they are used in lines handling different fluids.
- Other rubbers, such as EPDM, HNBR have lower chemical and temperature resistance than fluoropolymers and as a result likely prone to failure more often if used in the same processes - and are not suitable for more demanding applications for sealing equipment, such as O-rings.
- Polyolefins, such as polyethylene and polypropylene have good flexibility and chemical resistance, but their relatively low melting point and temperature resistance make them unsuitable for most of the applications that currently use fluoropolymers in pipe linings and sealing. Furthermore, their resistance to corrosion and chemicals reduces with increasing temperature, making them unsuitable for most of the applications of fluoropolymers.
- PVC has good temperature and chemical resistance, but not as good as those of fluoropolymers and may not be suitable for some more demanding applications.

¹¹ See: <https://www.crp.co.uk/wp-content/uploads/2020/06/Guide-to-the-Selection-of-Corrosion-Resisting-Non-Metallics.pdf>, accessed on 23 August 2023

¹² Ibid.

The discussion above on the technical feasibility of potential alternatives is presented from a broader point of view, in an attempt to cover the very large number of applications of fluoropolymers in the oil and gas industry supply chain.

The analysis of the case studies provides a more focused view of the feasibility of alternatives for three specific applications selected.

4.2.3 Safety considerations related to alternatives

The main safety considerations related to alternatives do not stem from any inherent hazards of the alternatives themselves. Most of the proposed alternatives considered for the fluoropolymer applications in ExxonMobil's operations have low hazard profiles and do not pose any direct danger to workers or the environment^{13 14}.

However, as mentioned in Section 4.2.2 on technical feasibility, most of these alternatives lack the durability and chemical/corrosion resistance of fluoropolymers. They perform worse in highly demanding applications involving extreme conditions and corrosive chemicals, so there is increased risk for potential accidental releases due to imperfect sealing or breaks or cracks.

In refineries and petrochemical processing facilities, fluoropolymer linings and sealing equipment are used on lines that transport corrosive or highly reactive chemicals, which, if released, may be harmful to the workplace or the environment. These chemicals need to be contained through durable and chemical-resistant sealing.

It should be noted that some of the considered alternatives may release breakdown products due to fatigue or exposure to high temperatures or reactive chemicals.

ExxonMobil handles highly flammable materials at a wide range of conditions in their processes, so they need to ensure that lines are leak-free, to prevent the risk of a fire or an explosion. If a seal with lower performance is used, the risk of an accidental release would increase.

In summary, potential alternatives may carry a higher risk for workers, the environment and the surrounding communities due to the lower performance and higher potential risk of leaks in harsh operating conditions.

4.2.4 Economic feasibility of alternatives

In terms of unit price, some potential alternatives to fluoropolymers are cheaper, though there are some, such as Inconel cladding and PEEK that are more expensive. It is generally agreed that fluoropolymers are more expensive than other sealing or lining polymer materials.

Despite their higher unit price, fluoropolymers are preferred for demanding applications due to their higher durability, reliability, and excellent performance in a broad range of conditions and chemicals. Fluoropolymers do not degrade or break down and thus tend to have a longer service life than components made from alternative materials. As a result, there is a lower rate of failures and, consequently, lower need for repair or replacement.

Therefore, over a facility's lifetime the overall cost for replacements, repairs and downtime due to failures can be lower when fluoropolymer linings and seals are used than with alternative materials.

¹³ Henry, B., Carlin, J., Hammerschmidt, J., Buck, R. C., Buxton, L., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymers of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management*, 14(3), 316–334. <https://doi.org/10.1002/ieam.4035>

¹⁴ S. Korzeniowski and all - A Critical Review of the Application of Polymer of Low Concern Regulatory Criteria to Fluoropolymers II: Fluoroplastics and Fluoroelastomers – *Integrated Environmental assessment and Management* - <https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4646>.

4.3 Conclusion

Fluoropolymer components used at all levels of the oil and gas industries supply chain are preferred for applications that involve a broad range of temperatures and pressures, constant contact with highly corrosive and highly reactive chemicals, and often mechanical stress. Fluoropolymers have a unique combination of excellent durability in a broad range of operating conditions, non-stick properties and very low coefficient of friction. These are the main reasons they are selected for demanding applications, where other materials cannot meet the performance and safety requirements.

In general, potential alternatives to fluoropolymers fail to meet the requirements for stability (at high temperatures and pressure), chemical resistance, or both. Their lower performance as linings or sealings would mean that use of alternative materials could result in potentially more frequent equipment failures, resulting in leaks of substances to the workplace and the environment. In addition, reduced performance could result in higher costs over time, as there would likely be a higher frequency for repairs and replacements.

It must be noted that linings, seals and other components made out of non-fluoropolymer materials are already in use by ExxonMobil in operations where operational conditions do not require that higher-performance fluoropolymers be used.

As a conclusion, due to the lack of technically feasible alternatives substitution of fluoropolymers in the majority of the applications at ExxonMobil's operations is not possible.

5. SOCIO-ECONOMIC ANALYSIS

5.1 Introductory Note

This socioeconomic impact assessment compares two scenarios, the 'continued use scenario' and 'limited-derogation scenario':

- **Continued use scenario:** Under this scenario, the requested time-unlimited derogations for uses of fluoropolymers are granted (i.e., the company can continue using fluoropolymers where required), which means use of fluoropolymers in equipment and infrastructure of upstream, transport, refining and petrochemical manufacturing operations in the entire oil and gas industry, as well as related industrial processes supporting lower carbon emissions can continue. The continued use scenario does not assume that all fluoropolymer uses will continue indefinitely.
- **Limited-derogation scenario:** Under this scenario, the restriction is implemented in its current form, and a time-limited derogation will be applicable for a small share of ExxonMobil's applications in exploration and production, and potentially transport operations. All other uses, e.g., in refinery, lubricant manufacturing petrochemicals, but also low carbon solutions will not be covered by a derogation.

From a geographical scope, emphasis has been placed predominantly upon describing the nature of impacts inside the EEA. This is based on clear information from ECHA's original SEA restrictions guidance, which highlights that *"In setting the geographical coverage and undertaking the assessment of impacts, it should be kept in mind that the final comitology decision... on whether or not to grant an authorisation will most likely focus mainly on impacts inside the EU. As a consequence, it is recommended that the emphasis be placed on describing and possibly quantifying what happens inside the EU"*¹⁵

Nevertheless, it must be noted that the oil and gas supply chain is very complex and impacts are rarely localised in one country or region. For example, exploration and production activities may take place within an EEA exclusive economic zone, refining in North America and specialised products may also be produced in the EEA or another region. As such, it is not always possible to accurately predict the extent of impacts if the analysis focuses only on a single region (here, the EEA).

Whilst the key focus of the SEA is considered to be EEA society as a whole, information is also provided regarding higher level direct impacts to ExxonMobil and its customers. This is in order to provide clarity regarding wider downstream and societal impacts. For example, in certain instances, direct impacts to ExxonMobil can also be associated with indirect impacts that will impact EEA society more widely. Such instances could include direct job losses to ExxonMobil within the EEA associated with the limited derogation scenario having an indirect effect on unemployment more widely within the EEA.

It is also noted that whilst efforts have been made to quantify impacts where possible, some of the impacts are described qualitatively.

The restriction proposal highlights that *"as specific information on costs of a ban of PFASs for the different actors associated with the addressed uses was scarce and mainly qualitative, the derogations and their duration were mainly based on the availability and applicability of alternatives to PFASs"*. ExxonMobil wishes to add that whilst the scope of applicable derogations to ExxonMobil within the restriction proposal is limited, significant information has been provided in the above analysis of alternatives which highlights the significant lack of technical and economic feasibility for substitution of fluoropolymers over a series of timeframes (associated with each of the uses in

¹⁵ ECHA (2008): Guidance on Socio-Economic Analysis – Restrictions Available at: https://www.echa.europa.eu/documents/10162/2324906/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d.

question). In this regard, the current SEA is provided to further support ExxonMobil's requests for derogations.

5.2 Continued use scenario (aligned with preferred derogations)

5.2.1 Introduction and scenario definition

The draft restriction proposal for PFAS includes a list of proposed and considered derogations with various degrees of broadness (or narrowness) of scope. Despite the use of fluoropolymers in several applications in ExxonMobil's operations, only a small share of these applications are currently considered for a derogation. Those proposed derogations that may be of relevance to the use of fluoropolymers in manufacturing are listed below:

- fluoropolymer applications in petroleum and mining industry until 13.5 years after EiF.
- textiles for the use in filtration and separation media used in high performance air and liquid applications in industrial or professional settings that require a combination of water and oil repellence until 6.5 years after EiF;
- lubricants where the use takes place under harsh conditions, or the use is needed for safe functioning and safety of equipment until 13.5 years after EiF;

Of the three derogations, only the first one appears to be suitable for a limited share of ExxonMobil's applications, as described in Section 3.1. The derogation appears to be relatively broad, based on its title, but the description in Annexes A and E to the restriction proposal indicates that it only covers limited upstream operations, while refining and petrochemical processes are **not** covered by the derogation.

More specifically, section A.3.16.1 in Annex A to the restriction proposal discusses uses and applications that are related to upstream operations, such as production and transportation of crude oil, with a limited focus on offshore operations (e.g., uses mentioned in section A.3.16.1.1 and Table A.61 may be relevant to drilling or production operations). Nevertheless, there is no explicit reference to refining or petrochemical applications, other than to comment that it was unclear if they are covered by the chemical processing use category (which uses PTFE sealings), which was not analysed at all in the restriction proposal annexes.

As such, the majority of ExxonMobil's uses in refining and downstream operations would be out of scope of a derogation and the full scope of upstream operation as defined by petroleum and mining may still not be covered.

Considering the above, a continued use scenario for the uses discussed in this report would be ensured by a time-unlimited derogation worded as follows:

Use of fluoropolymers in equipment and infrastructure of the entire oil and gas industry including but not limited to upstream, transport, refining and petrochemical operations.

5.2.2 Market and business trend considerations

5.2.2.1 European market

EU demand for oil was 541.8 billion tonnes in 2022, exhibiting recovery growth after a sharp decline in 2020 due to the Covid-19 pandemic, but has still to reach 2019 levels¹⁶. Overall, Europe and Eurasia (excluding Russia) accounted for approximately 17% of the global refining capacity in 2022. The main

¹⁶ Fuels Europe (2023). 2023 Statistical report. Available online at: https://www.fuelseurope.eu/uploads/files/modules/documents/file/1689691754_ojbWJAv2G1bW7rw43TrQajsr4pfV1m5lrbhOfI_S.pdf, accessed on 22 August 2023

driver for growth is expected to be the increasing demand for jet fuel / kerosene, while the emergence of biofuels and electric vehicles could impact overall demand^{17 18}.

In total, 75 refineries were operational in Europe (EU, UK, Norway and Switzerland) in 2022. Figure 5-1 shows a map with all the refineries and steam cracker sites in Europe.

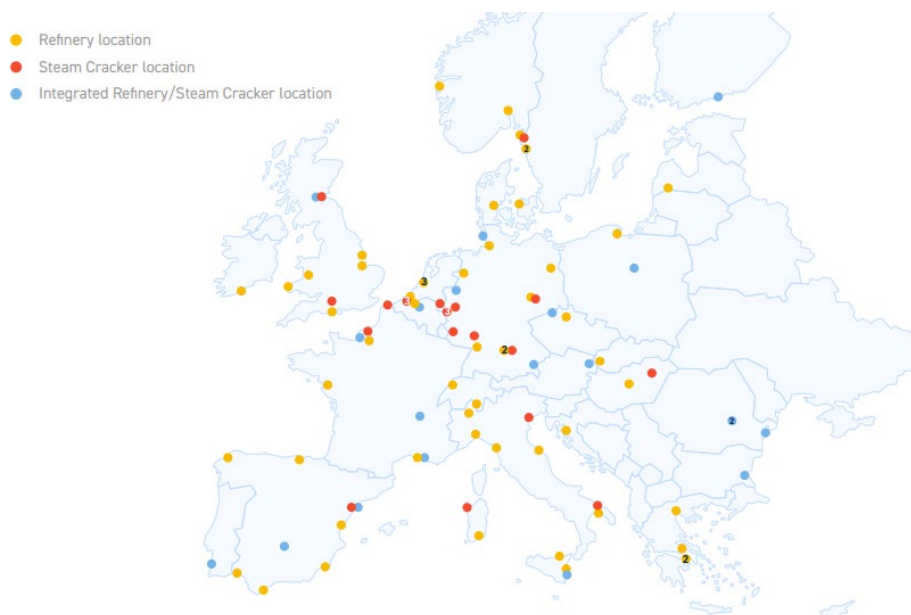


Figure 5-1. Refinery and steam cracker locations in Europe¹⁹

The downstream EU petrochemicals industry was valued at €153.4 billion in 2021, accounting for more than a quarter of the total value of chemicals produced in the EU, according to CEFIC. It is also the sector with the highest added value in the chemicals sector in the EU, with approximately €45 billion in 2021. Investment in the sector was approximately €6.4 billion in 2020²⁰.

Overall, the oil and gas supply chain, in which most of ExxonMobil's operations lie, is still a strong factor in the EEA and the global economy, with total operations in the billions of euros creating and maintaining thousands of jobs in the EEA.

5.2.2.2 ExxonMobil operations and investment

In 2022, ExxonMobil's share capacity for seven refineries in Europe (six in the EEA and one in the UK) was approximately 1.3 million barrels per day. This accounts for approximately 29% of ExxonMobil's worldwide refining capacity. EEA refining locations of ExxonMobil are in Belgium, France, Germany, Italy and the Netherlands²¹.

¹⁷ See; <https://www.mordorintelligence.com/industry-reports/europe-refined-petroleum-products-market#:~:text=The%20European%20refined%20petroleum%20products%20market%20is%20expected%20to%20register,has%20reached%20pre%20pandemic%20levels>, accessed on 23 August 2023

¹⁸ IEA (2023). Oil market report. Available online at: https://iea.blob.core.windows.net/assets/6b994ae3-17fe-4a44-8bb8-eb1217cc4604/-18JAN2023_OilMarketReport.pdf, accessed on 23 August 2023

¹⁹ Fuels Europe (2023). 2023 Statistical report. Available online at: https://www.fuelsEurope.eu/uploads/files/modules/documents/file/1689691754_ojbWJAv2G1bW7rw43TrQajsrr4pfV1m5lrbhOfI_S.pdf, accessed on 22 August 2023

²⁰ CEFIC (2023). 2023 Facts and Figures of the European chemical industry. Available online at: <https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/>, accessed on 22 August 2023

²¹ ExxonMobil (2022). Annual report 2022. Available online at: https://d1io3yog0oux5.cloudfront.net/_c1ccf2aa866063418f50eda6c368c3a8/exxonmobil/db/2301/22049/annual_report/2022-Annual-Report.pdf, accessed on 23 August 2023

Upstream, ExxonMobil's net acreage in Germany was 1.4 million onshore acres at year-end 2022. In the Netherlands, its interest in licences totalled 1.4 million acres at year end 2022, of which 0.4 million acres were offshore.

Downstream, ExxonMobil's chemical complex capacity in Europe was 2.4 Mtons per year, of which 0.4 Mtons ethylene production, 1.3 Mtons polyethylene and 0.3 Mtons polypropylene production.

In addition to the existing operations, ExxonMobil is continuing investing in projects that will rebalance supply and demand in the oil and gas market, and achieve long-term energy security, through a balanced, diversified and sustained investment in both transitional energy sources and lower-emission solutions throughout the energy transition. Exxon Mobil Corporation has invested for decades to develop new energy resources to help meet society's growing needs. Between 2017 and 2021, Exxon Mobil Corporation invested \$118 billion to develop global energy resources (more than double their earnings - \$55 billion - in the same period). Even during the global pandemic, when Exxon Mobil Corporation lost \$22 billion, there was continued investment in the development of new energy resources with an expectation that the economy and global demand would eventually rebound.²²

Exxon Mobil Corporation plans to invest approximately \$17 billion from 2022 through 2027 on its own emissions reductions and accretive third-party lower-emission initiatives.²³

About two-thirds of the products ExxonMobil makes are used by commercial and industrial companies - including electric utilities, trucking and other commercial transportation, and heavy industries like steel and cement.

Reducing emissions in these sectors will be key to meeting society's climate goals. That's why Exxon Mobil Corporation is scaling up low carbon solutions, such as carbon capture and storage, and the next generation of industrial fuels - like hydrogen - which can help industries meet their emissions-reduction goals while continuing to provide essential products for the world²⁴.

Exxon Mobil Corporation, with advances in technology and the support of clear and consistent government policies, aims to use many of these same solutions to advance their own 2050 net-zero operated Scope 1 and 2 ambition.²⁵ Industry solutions such as those offered by ExxonMobil are necessary for the EU to achieve the ambition to have net-zero emissions by 2050 as expressed in the EU Green Deal. An example of such contribution is the reduction of methane by 95% since 2000²⁶.

5.2.3 Risks associated with continued use.

ExxonMobil is currently using millions of fluoropolymer components (estimations using available data vary between 1 and 5 million components, but the number can be even larger) in their EEA operations. Depending on the application, they have service lives ranging from 10 to 30 years and even longer as discussed in Section 3.3, the way that fluoropolymers are used in ExxonMobil's operations, in combination with their excellent durability and physicochemical properties, prevents releases during their service life. Fluoropolymers are not volatile and do not erode under normal operating conditions. Fluoropolymer linings and flexible hose sheaths are used as internal components and are not exposed to the environment, so even in subsea applications (e.g., for flexible pipe, as in Case Study 1) there is practically no possibility of emission, unless there is larger structural

²² ExxonMobil website – Oil and gas supply. Available online at: <https://corporate.exxonmobil.com/what-we-do/energy-supply>, accessed on 23 August 2023

²³ [ExxonMobil announces corporate plan — Company expects to double earnings and cash flow potential by 2027, increases investments in lower-emissions efforts](https://corporate.exxonmobil.com/what-we-do/delivering-industrial-solutions/carbon-capture-and-storage/ccs-in-action)

²⁴ ExxonMobil website – CCS in action. Available online at: <https://corporate.exxonmobil.com/what-we-do/delivering-industrial-solutions/carbon-capture-and-storage/ccs-in-action>, accessed on 22 August 2023

²⁵ See: <https://corporate.exxonmobil.com/-/media/global/files/advancing-climate-solutions-progress-report/2023/2023-advancing-climate-solutions-progress-report.pdf>

²⁶ See: <https://energyfactor.exxonmobil.eu/science-technology/reducing-methane-emissions-in-germany/>

damage to the whole pipe, something that the anti-corrosion properties of fluoropolymers assist in preventing.

It must be noted that the excellent durability, chemical resistance and overall sealing and anti-stick properties of fluoropolymers minimise the risk of accidental releases of products from line connections or other damaged equipment to the workplace or the environment.

All end-of-life equipment must be disposed of according to the requirements of national legislation.

ExxonMobil complies with all applicable laws and regulations regarding collecting, managing and treating waste generated by their activities and operations along the oil and gas supply chain. If required by legislation, end of life equipment containing solid fluoropolymer components, undergo waste management, which includes segregation, recycling or appropriate disposal, according to local and national legislation.

5.3 Limited derogation scenario (aligned with current ECHA Restriction Proposal)

5.3.1 Introduction and scenario definition

As discussed in Section 5.2.1, the only proposed derogation that is expected to cover some of ExxonMobil's operations is the one for fluoropolymer use in the petroleum and mining industry. However, this only seems to cover limited extraction operations (upstream). The description of the derogation also creates uncertainty on whether the derogation even covers all uses across upstream operations. In either case, there are no derogations for ExxonMobil's uses of fluoropolymers in refining and petrochemical applications and associated services.

Due to the large number of applications in ExxonMobil facilities, analysing each specific process for the importance of use of fluoropolymers is not practical, also due to the fact that several of these processes are proprietary and cannot be described in detail. Three case studies have been selected and describe the expected impacts for these particular applications. These are currently available in Sections 7 to 9.

In addition, arguments on specific fluoropolymer uses in ExxonMobil's operations have been developed and presented by relevant EU and national associations in their submissions to the OPC, as presented in **Table 3-1**.

This section also presents a high-level, global, assessment of the limited derogation scenario where the fluoropolymer applications are used for the whole of the ExxonMobil set of operations.

If the PFAS restriction proposal remains as is, ExxonMobil will not be allowed to use fluoropolymer components, linings or coatings in their equipment and processes after the restriction's entry into force. This will mean that, on one hand ExxonMobil will not be able to construct new wells, process facilities, or process stream transport lines using fluoropolymers, and they will not be allowed to use fluoropolymer spare parts to replace or repair equipment in their existing operations. Additionally uses in the areas where ExxonMobil is starting their Low Carbon Solutions business (Carbon Capture, Carbon Storage, and Hydrogen) may be impacted.

ExxonMobil has the following potential options in such a situation:

- Utilise components manufactured from alternative materials, where available. As discussed in Section 4, the available alternatives for the various applications cannot perform as well as fluoropolymers. Using them could result in lower performance and potentially higher risk of releases and equipment failure. In addition, it may not be possible to meet some of the performance and safety specifications in the industry and country standards used (e.g., API, ISO standards, as discussed in Section 3.2.3).
- Over time, if suitable alternatives do not become available on the market that meet equivalent performance standards, certain process lines relying on the use of fluoropolymers in EEA

facilities may potentially stop after their service life is over and shift such production to non-EEA facilities. Here, the integrated structure of refineries and, in some cases, petrochemical plants, must be noted. Refineries mostly consist of continuous processes, with a constant flow of feedstock, outputs and processing aids. Shutting down or decommissioning an isolated process streamline or process could likely disrupt the whole production in the refinery and downstream. For example, at a refinery at Fawley in the UK is manufacturing a series of products used as medical device components or in manufacturing of pharmaceuticals. Medical grade halobutyl rubber, for example is a material used in vials for Covid-19 vaccines, while methyl ethyl ketone (MEK) is widely used in pharmaceutical synthesis. Both these products require fluoropolymer-lined pipe to prevent corrosion²⁷.

- Over time, if suitable alternatives do not become available on the market that meet performance standards, potentially shut down whole facilities (exploration, production, refining, and petrochemical) as a result of the lack of availability of performance- and safety-critical fluoropolymer components. This would likely be considered as a last resort and is unlikely to be the case in this scenario. Nevertheless, it cannot be completely ruled out.

5.3.2 Summary of consequences of limited derogations

Alternative materials to fluoropolymers in general do not have the same level of durability and chemical / corrosion resistance. As a result, they are expected to have shorter service life or no service life and greater failure rate, particularly in applications with extreme conditions, in which fluoropolymers are typically used. This could result in more frequent repairs and replacements, which in turn would require a significant increase in the quantity of new components that will need to be manufactured and of generated waste. In some cases, it could be possible that the incompatibility of the alternative material may cause accidental releases leading to a potential immediate shutdown.

In addition, it is expected that there will be a potentially higher risk of releases by the use of less effective materials. The lines using fluoropolymer linings and seals typically transport process flows that can damage the metallic equipment, such as corrosive and reactive chemicals, and hydrocarbons. Some of these chemicals can also be hazardous to human health and the environment.

In operational terms, use of less effective materials, and the subsequent potential for more frequent incidents, may result in more frequent and longer downtimes in production, impacting in the end the total output of the facility. In that case, it is unlikely that ExxonMobil would select to use such materials, as they need to be certain that any material used must be able to meet the very strict safety and reliability specifications. If it is not possible to meet them, it is likely that the particular line or equipment will not be used until a suitable alternative can be developed – a process that can take many years and may have little chance of being successful.

In addition, many new investments in conventional and low-emission technologies by ExxonMobil may be delayed, as they would need to be redesigned for use of non-fluoropolymer materials. In some cases, construction may have already started, which would make re-design almost impossible. In general, it is progressively more expensive and time-consuming to make design changes early in a project's timeline, moving from conception, to design, planning, construction and finally to commissioning.

Overall, a limited derogation scenario would lead to significant disruption in ExxonMobil's existing and future operations along the whole oil and gas supply chain, including in some lines critical for the EEA economy, such as fuels and additives, as well as feedstock for petrochemical and other organic industries.

²⁷ See: <https://www.exxonmobil.co.uk/-/media/UnitedKingdom/Files/Fawley/Press-Releases/ExxonMobil-Fawley-helps-fight-against-COVID-19.pdf>

5.3.3 Societal costs associated with limited derogations.

The three case studies in Section 7 to 9 provide a more specific, description of potential impacts in a limited derogation scenario. This section will provide a high-level description of the potential overall impacts relevant to all ExxonMobil's operations.

5.3.3.1 Impacts for ExxonMobil

Fluoropolymers are used throughout the ExxonMobil operations including, but not limited to, upstream, refining and downstream petrochemical processes. In a limited derogation scenario, ExxonMobil will probably still be able to continue limited upstream operations in the EEA, but their refining and petrochemical operations will likely be impacted, with overall production efficiency potentially dropping. All refinery products may be affected in such a situation because of the integration of processing units in refineries.

As discussed in Section 5.2.2.2, ExxonMobil refineries in the EEA have a capacity of 1.3 million barrels per day²⁸, so it is possible that a disruption in the refinery operations could result in a lower processing capacity for ExxonMobil.

ExxonMobil's petrochemical facilities also rely on feedstock from refineries. In some locations, there are integrated petrochemical processing installations which are fed directly by the refinery output, while in other locations they rely on regular deliveries. In both cases, however, the potentially increased downtime in the upstream processes and disruption in the supply of feedstock would also disrupt the process. In the integrated processes, which are typically running continuously, the impact could be larger, with increased energy and material consumption every time that processes are forced to stop and then start up again.

In summary, a limited derogation scenario could result in significant revenue losses or potentially increase in process safety incidents. Impacts may become even larger if certain processing lines are forced to shut down in the EEA and supply of up to 500 different products is disrupted. ExxonMobil estimates that more than half of their output may be affected and may be lost if the current restriction proposal remains.

In addition, lack of access to fluoropolymer materials may also delay or even cancel projects in new facilities and extraction operations, until alternative materials or designs are sufficiently validated and approved.

5.3.3.2 Impacts for workers and general public

The potentially higher risk of equipment failures and releases from the use of less durable equipment could result in exposure of workers, the environment and the surrounding communities to different chemicals from ExxonMobil's processes.

It should be noted, however, that ExxonMobil per its Safety Policy is committed to conducting its business in a manner that protects the safety of employees, others involved in its operations, customers and the public and complying with all applicable laws and regulations. In doing so, maintains high quality and safety standards in their operations, complying with the requirements of applicable industry standards, such as API and ISO, as discussed in Section 3.2.3.

5.3.3.3 Impacts for ExxonMobil customers

Refineries and petrochemical facilities are the suppliers of a large share of downstream industries. Furthermore, they are currently producing fuel for most of the transport industry, as well as for power generation for manufacturing and the general population. Disruption in the production process of these essential products could potentially create insecurity in the oils and gas industry supply chain,

²⁸ ExxonMobil (2023). Annual report 2022. Available online at: https://d1io3yog0oux5.cloudfront.net/c1ccf2aa866063418f50eda6c368c3a8/exxonmobil/db/2301/22049/annual_report/2022-Annual-Report.pdf, accessed on 23 August 2023

with downstream users having to look for alternative sources of feedstock, or fuel. In most cases, they will look to source the required products from non-EEA suppliers, as it is expected that the impacts expected to be faced by ExxonMobil will be felt across the industry in the EEA.

In general, downstream users of ExxonMobil's products may face significant impacts to their operations, as they may be facing potential reduced supply of required feedstock.

Our role in the energy transition is to leverage the scope and expertise of ExxonMobil, focusing on carbon capture and storage, hydrogen and second-generation biofuels to deliver tailored solutions for their customers. Whilst this business is in its early stages of development, technology solutions will be offered to their customers which rely on many of the common processes found in the upstream, refining and petrochemical sectors where fluoropolymers are used.

5.3.3.4 Impacts for the wider EU society and economy

ExxonMobil's upstream operations contribute to the supply of EEA crude oil and gas to feed the EEA-based refineries. Were they to stop, non-EEA feedstock sourcing for refineries would need to increase, thus potentially reducing the security of supply for the EEA. Limited derogation scenarios would extend to the broader oil and gas industry across the EEA as all operators would have similar restrictions concurrently, significantly increasing the disruption of oil and gas products and services to the wider EU society.

ExxonMobil also invests strongly in developing low-carbon solutions, such as hydrogen generation and carbon storage, which are necessary to achieve the EU ambition to have net-zero emissions by 2050. A restriction in the use of fluoropolymers in oil and gas operations would prevent the development of these technologies in multiple ways.

Firstly, it could affect overall ExxonMobil operations and their revenue, which could reduce the available capital for investment.

Fluoropolymer components are also critical for such low-carbon technologies, as they are used in hydrolysis and fuel cell membranes for hydrogen generation, in battery binders for energy storage, and potentially as seals in various applications. A ban in their use would mean that it will not be possible to develop these technologies in the EEA, limiting the EU's ability to meet its net-zero ambitions in the short- and mid-term. Hydrogen Europe has a more extensive discussion on the importance of fluoropolymers for the future of hydrogen in the EU²⁹.

²⁹ Hydrogen Europe (2023). Hydrogen Europe Position Paper on PFAS - The importance of fluoropolymers across the hydrogen value chain and impacts of the proposed PFAS restriction for the hydrogen sector. Available online at: https://hydrogeneurope.eu/wp-content/uploads/2023/02/Hydrogen-Europe-position-paper-on-PFAS-ban_v12_FINAL.pdf, accessed on 11 September 2023.

6. SUMMARY

ExxonMobil operations take place under extreme operating conditions, such as very high temperatures and pressures, mechanical fatigue and stress, as well as in the presence of corrosive chemicals. It is therefore imperative that the equipment used withstands these harsh conditions over long periods, which can reach 30 years in some cases (e.g., offshore drilling and transportation).

Fluoropolymers are critical materials used in equipment necessary for the safe and reliable operation in oil and gas value chain sites. They exhibit a unique combination of temperature and chemical resistance, along with mechanical durability, which makes them ideal for use under a wide range of environmental conditions and contact with corrosive chemicals on a constant basis.

The PFAS restriction proposal proposes a derogation for the use of fluoropolymers in petroleum and mining industry until 13.5 years after EiF. This proposed derogation only covers part of the exploration and production (i.e., upstream) stage, while the applications in transportation, refining and petrochemical operations appear not to be included in the scope of a derogation. In addition, even though the dossier submitters propose a long derogation period of 13.5 years, it is very likely that suitable alternatives will **not** be available for all uses and applications after the end of this period because of the very strict specifications the oil and gas industry has to comply with in all their processes.

If the restriction text remains as proposed, it is very likely that the whole oil and gas value chain will be impacted, as they will not have access to necessary equipment or spare parts to perform their operations safely and reliably. If they were to use materials with different properties and lower resistances to temperature, chemicals or mechanical stress, it could result in more frequent need for repair or replacement. In some cases, e.g., pipe used in offshore upstream installations, repair may not even be feasible, so it would be essential that the alternative material performs for the whole of its service life. Therefore, if no additional derogation is granted, the whole oil and gas (ExxonMobil) supply chain in the EEA could be disrupted.

The oil and gas industry provides many chemicals and products that are essential for daily life, and the industry has been supplying the EEA and the rest of the world with energy products, lubricants, plastics and specialty chemicals continuously for decades. As industry evolved, fluoropolymers have become an essential part of the oil and gas industry supply chain, enabling safe and reliable operations in all refineries, petrochemical plants and exploration sites. Their continued use is thus critical to maintain this steady supply of diverse and essential petroleum and chemical products and services. Their future use in a lower carbon industry will be required to provide customers with a range of options to tackle the challenge of reducing emissions in their operations.

Therefore, as the existing Derogation does not cover uses adequately in the entire oil and gas industry, ExxonMobil would request as per the details given in the Socio-Economic Assessment section of this report, that a Continued Use Scenario be adopted, with a time-unlimited derogation encompassing the use of fluoropolymers in the entire oil and gas industry as defined in this report. It can be added to the restriction proposal as follows:

Use of fluoropolymers in equipment and infrastructure of the entire oil and gas industry including but not limited to upstream, transport, refining and petrochemical operations.

7. CASE STUDY 1 – UPSTREAM

7.1 Description of use

Upstream operations may use flexible pipes in various steps of their operations. These pipes are used downhole for extraction and to transport the extracted crude oil and gas to storage facilities. Flexible pipes are also used to inject fluids (e.g., water) and gases into reservoirs to assist production and also to facilitate gas storage.

Flexible pipes are used in offshore facilities in non-EEA locations, and it is possible that future EEA exploration, production and gas storage activities may also require them. Flexible pipes have marked advantages over metallic ones in that they have higher resistance to corrosion over their very long lifetimes (20-30 years) and require few connections, minimising the risk of equipment failure. Most importantly, they are much more resistant to fatigue caused by the dynamic conditions on the ocean, such as waves, underwater currents and high-water pressure, which can reach more than 200 atmospheres at great depths. In addition, their lower weight also makes them more suitable for pipe laying at greater depths, as the whole pipe would be lighter and easier to handle.

PVDF is used as a pressure sheath in the pipe to ensure containment of reservoir fluids and gases in the bore of the pipe. This is an inner layer, that has no contact with the external environment.

PTFE and fluoroelastomer (FKM, FFKM) seals are also used at the end terminations of the flexible pipes to ensure tight fit of the pipe with the storage tank and minimise the risk of releases.

7.2 Performance requirements for fluoropolymers

The fluoropolymer components of the flexible pipes used in offshore production sites must maintain their functionalities throughout the pipe's expected lifetime of up to 30 years. Any alternative will thus need to be durable enough against the expected conditions of operation, but also be flexible enough to withstand the mechanical stress applied on the pipe. More specifically, the pressure sheath and sealings used in flexible pipes need to meet the following specifications.

- No degradation after prolonged exposure at the high temperatures and pressures. As per ISO 23936-1, they should be able to withstand temperatures of 90-130 °C and pressures of 5,000 psi³⁰. The materials used must not have a too low melting point and must maintain their shape and size under a broad range of pressures.
- As many of the pipes are intended to be used underwater in marine environments or in environments where corrosive agents may be present, the materials used must also be resistant to corrosion and oxidation (e.g., from sea water).
- The material of the pressure sheath must also be sufficiently flexible to withstand the bending stress from installation and operation of the pipe. If it is too rigid, it will crack and not be able to protect the pipe from the high pressure.

7.3 Assessment of alternatives

A number of alternative materials have been considered as substitutes to PVDF in flexible pipes. The assessment of these materials has been based on ExxonMobil's expert knowledge of the field, combined with the expertise of their suppliers in the development of potentially suitable materials. In general, it can be concluded that the identified potential alternatives cannot meet all the requirements mentioned in Section 7.2. More specifically:

- Certain alternatives, such as polyethylene and polyamide cannot operate safely in the same high temperatures and high pressures (HPHT) environment as PVDF, because they have too low

³⁰ ISO 23936-1:2022. Oil and gas industries including lower carbon energy — Non-metallic materials in contact with media related to oil and gas production — Part 1: Thermoplastics.

melting points or low resistance to the HPHT environment encountered during service of a flexible pipe. They also lack the mechanical durability necessary.

- On the other hand, those alternatives that can operate safely in the expected HPHT environment due to their very good temperature resistance, such as PEEK, are too stiff and, as a result, cannot be used in flexible pipes.

Use of an alternative that does not meet the safety and performance requirements could result in a much worse quality of the flexible pipe, which may not be sufficiently flexible or durable against its operational conditions, thus shortening its actual service life and increasing the potential risk of spills of crude oil or leaks of natural gas.

Another option would be to switch back to the use of metallic piping. However, these pipes offer much less flexibility and need many more connections, thus increasing the risk of substances escaping, especially if the use of fluoropolymer seals is not permitted.

7.4 Substitution potential

It is practically impossible to substitute fluoropolymer components in production platforms already in operation, especially as far as the pressure sheath in the pipe is concerned. This would require the whole pipe to be removed and replaced by a new one, with increased material consumption and waste generation, as well as a significant disruption in the upstream operations.

The only potential option for substitution is to avoid using fluoropolymers in any new installations. This, however, would require that a suitable alternative has been identified and validated before it is decided if it can be used. Such a process takes several years, even after a potential alternative has been identified.

As discussed in Section 7.3, none of the known potential alternatives is considered suitable for use in flexible pipes, so in total, substitution could take longer than the proposed derogation of 13.5 years for certain applications.

7.5 Limited-derogation scenario

The limited-derogation scenario, and the expected impacts, will need to be examined from two points of view: for new installations, and for existing ones.

Under a limited-derogation scenario, in which it will not be possible to use fluoropolymers in new constructions or equipment, it will not be possible for ExxonMobil to set up new upstream sites, including offshore in EEA waters, that need to use flexible pipes and fluoropolymer seals. ExxonMobil would not be able to use alternative materials at HPHT wells, as they would not meet the reliability and safety requirements dictated by industry standards and national regulations. Having no such options, therefore, could mean that such operations would not be possible to be undertaken in EEA waters. This would also extend to other wells that may require the use of PVDF, as the use of that plastic is dictated by the water depth and reservoir temperature as well as by the weight of the riser and the potential for fatigue (e.g., from waves and currents).

Similarly, while it will still be possible to continue using fluoropolymers in equipment of existing installations, it will not be possible to use fluoropolymer spare parts and replacements in case of a component failure. This could result in much shortened service life for flexible pipe installations.

7.6 Assessment of impacts

7.6.1 Assessment of residual risks

During its service life, the PVDF pressure sheath is completely enclosed, as it is an inner layer of the flexible pipe not in contact with the external environment. Furthermore, operating temperatures are much lower than the material's melting point and PVDF does not break down due to temperature or

age over time. As a result, there are no expected PVDF emissions to the environment during the well's lifetime.

The same applies to the PTFE and fluoroelastomer sealing equipment, as the fluoropolymers used are very resistant to temperature, chemicals and environmental conditions and are not expected to release any vapours or particles throughout their service life.

At the end-of-life phase, it must be noted that ExxonMobil complies with all applicable laws and regulations regarding the management of their operations and the handling of waste.

7.6.2 Overview of impacts of no-derogation

In case of a no-derogation scenario, it is expected that the lack of spare parts and replacements for existing installations, along with the inability of ExxonMobil and industry to use high-performance flexible pipes containing PVDF in EEA operations and possibly globally, would result in lower reliability of the lines, with more frequent breakdowns and significant shorter service lives for the equipment.

Furthermore, HPHT wells and offshore sites that need to protect the piping against fatigue damage due to the conditions in the ocean (e.g., currents, very high pressures at large depths, waves) essentially demand the use of flexible pipes with PVDF and the use of fluoropolymer sealing. If fluoropolymers cannot be used in such installations, it could restrict the potential output of such reservoirs. Work under HPHT or high mechanical stress conditions needs to be carried out using specialised equipment and procedures, as the inherent risks in these operations are much greater than in conventional wells. Use of fluoropolymers has thus enabled the exploitation of deeper and higher temperature wells, thus increasing the available oil and gas reserves and ensuring global (and European) supply in the coming decades.

Therefore, a no-derogation scenario could impact the overall supply of crude oil and gas from HPHT wells, which could, in consequence, affect the EEA's security of supply.

7.7 Summary

Use of PVDF pressure sheaths and PTFE and fluoropolymer seals in flexible pipes is critical for the implementation of these pipes in oil and gas operations, particularly in offshore and HPHT wells, with very harsh conditions present.

Those extreme temperature, pressure, environmental and mechanical stress conditions prevent the use of alternative materials, as they cannot meet the durability and flexibility requirements. Using an alternative material would result in lower reliability and shorter lifetimes of the flexible pipe and the upstream operation in general.

Therefore, in a no-derogation scenario, it is very likely that the overall output of upstream operations, particularly in HPHT wells could be affected, as a result of the lower reliability and shorter lifetimes of alternative materials and equipment. It is thus likely that the industry may decide not to take the risk of using a lower quality material, which could affect the EEA's security of oil and gas supply.

8. CASE STUDY 2 – REFINING

8.1 Description of use

ExxonMobil uses fluoropolymer-lined components, such as valves and pumps, and fluoropolymer sealing components, such as seals and gaskets to transport various process streams during manufacturing of finished products, such as fuels and lubricants in their refineries in the EEA. The process streams include corrosive substances, such as sulphuric acid and sodium hydroxide, and hydrocarbons, at temperatures that can be as high as 300 °C. The process streams transported with this equipment are relevant to the majority of the operations in a refinery. More specifically, transport operations include:

- Crude oil from storage to refinery.
- Hydrocarbon streams within the refinery (e.g., from atmospheric and vacuum distillation column) to downstream operational units and to a petrochemical plant.
- Finished products and hydrocarbons to terminals for storage, loading, sales and retail.
- Hydrocarbon streams within the chemical plant and also to downstream customers.

Liners for valves can be made out of various different fluoropolymers, depending on the performance and safety requirements. Typical materials used for that purpose include PTFE, PVDF, ETFE copolymer, ECTFE copolymer, PFA and FEP. The sealing components are usually made of fluoroelastomers (FKM), perfluoroelastomers (FFKM) and PTFE.

8.2 Performance requirements

The fluoropolymer components used by ExxonMobil in refining need to be able to withstand extreme conditions for prolonged periods of time. They must be able to maintain their sealing properties or corrosion protection at very high temperatures, often reaching 300 °C and in the presence of very reactive and corrosive substances. This often means that the material does not deform, expand or break down in the presence of high temperature, pressure or mechanical forces.

For many of the components and linings, the specifications with regards to their flexibility, durability, chemical resistance and stability over a wide temperature range are described in performance and safety standards, such as those published by the API (indicative list in Appendix 1) or ISO. Some standards relevant to valves and seals are listed below:

- ISO 23936-2:2011 Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 2: Elastomers
- ISO 16961:2015 Petroleum, petrochemical and natural gas industries — Internal coating and lining of steel storage tanks.
- API 551 (2ed) requires refineries to effectively seal instrumentation and refers to grades resistant to temperature steam and hazardous atmospheres, while specific PFAS materials (e.g., PVDF) are listed.
- API 553 (2ed) describes how fluoropolymers and fluoroelastomers are essential in gaskets and valves and contribute to safe operations in refineries and reduce fugitive emissions which improve environmental performance.
- API 608 (5ed) / 609 (9ed) & 610 (12ed) describes how essential PTFE is for valves & pumps in the petrochemical industry, where it is used in lining, seats and packing, and again describes why PTFE is used as a component to ensure safe operations and reduce emissions when dealing with hazardous materials.
- API 650 (13ed) describes the essentiality of PFAS materials in the seals/gaskets of oil and gas storage tankage.

8.3 Assessment of alternatives

As mentioned in Section 8.2, valve and sealing components must meet very strict performance specifications, under very harsh conditions of use. As a result, it is very difficult, if not impossible to identify a suitable alternative for these applications.

- Potential alternatives to valve and pump applications include other polymeric materials, such as polyphenylene sulphide (PPS), polyethylene, polypropylene and polyether etherketone (PEEK). However, they are not stable at higher temperatures, and do not have the same level of resistance to chemicals as fluoropolymers. If they were used instead of fluoropolymers, performance of valves and pumps would decline and there may be a higher risk of potential releases and material failures.
- Metallic sealings, such as those made of Inconel and other high alloy materials may be suitable in some applications, but that depends on the particular use. Using those, usually expensive and difficult to procure, materials in sealing and gasket applications would require extensive re-design of the components and elaborate retrofitting of the pipeline. They may not be suitable for pipes where there are lots of vibrations, as this would shake the more rigid sealings, such as metallic, and would take them out of position, which could lead to a release. Many joints need to be flexible to absorb those vibrations and for that reason rigid systems are usually applied in limited uses.
- For seals and gaskets, various elastomers have been proposed as potential alternatives. These include nitrile butadiene rubber (NBR), hydrogenated NBR, and silicone rubber (VMQ). However, they do not have the combination of temperature and chemical resistance that fluoropolymers, such as PTFE, FKM and FFKM have. Most do not have the level of temperature stability needed to effectively seal joints and connections, while those that do have that stability, such as silicone rubber, lack the required chemical / corrosion resistance.

Overall, the available alternatives are not suitable for the very demanding applications that fluoropolymers are used in refineries.

It should be noted here that fluoropolymers are selected because of their superior performance and durability, despite being more expensive than some of the alternatives. They are used where it is expected that other, less expensive materials would not meet the performance and safety requirements arising from safety and reliability standards (and in some cases national legislation). Refinery operations have high safety standards, due to the physicochemical and toxicological hazards of the chemicals they process. As a result, they need to minimise the risk of any leak and material failure that could lead to a potential accident or environmental impact.

8.4 Substitution potential

As discussed in the previous section 8.3, there are currently no technically feasible alternatives for the uses of fluoropolymers in valves, pumps and sealings. Considering the regulatory activities around fluoropolymers, ExxonMobil and other industry members have evaluated potential alternatives for substitution. However, even if a technically and economically feasible alternative was available, substitution in all applications is a process that could take several years.

If an alternative to a fluoropolymer component was available, it could take up to 12 years for it to be introduced in the manufacturing process. The typical steps in this process are:

- Research and refinement of the potential alternative (estimated at approx. 6 years)
- Pilot deployment (estimated at approx. 1 year)
- Type standards writing and approval (estimated at approx. 3 years)
- Replacement manufacturing build-up (estimated at approx. 1 year)

- Roll out as fluoropolymer components (estimated at approx. 1 year). This process can take place gradually over several years, as fluoropolymer components currently in use reach the end of their service life.

8.5 No-derogation scenario

The no-derogation scenario, and the expected impacts, will need to be examined from two points of view: for new installations, and for existing ones.

Under a no-derogation scenario, in which it will not be possible to use fluoropolymers in new installations or equipment, it will not be possible for ExxonMobil to set up new processing and transport lines, as it would not be possible to use fluoropolymer components. In such a case, ExxonMobil may be forced to use alternative materials, which will lack the durability of fluoropolymers and could impact the process output and potentially increase the risk of equipment failure.

Similarly, while it will still be possible to continue using fluoropolymers in existing installations, it will not be possible to acquire fluoropolymer spare parts and replacements with the potential restrictions on the manufacture and import in case of a replacement for a component failure or repair.

8.6 Assessment of impacts

8.6.1 Assessment of residual risks

Due to the high durability and chemical resistance of fluoropolymers, the components and linings made out of them do not degrade or erode during their service life. They are also very stable at high temperatures, so they do not release any vapours during use. As such, there is very low chance of fluoropolymer emissions during their very long service lives, under normal operating conditions.

At the end-of-life phase, it must be noted that ExxonMobil complies with all applicable laws and regulations regarding the management of their operations and the handling of waste. For example, there are certain criteria on specific waste management for certain PFAS compounds within European Union Regulation (EU) 2019/1021 on Persistent Organic Pollutants. There are some Member States who have also implemented additional (either national or regional) requirements for management of PFAS impacted wastes.

If enhanced requirements are needed for management of fluoropolymers these would be managed within ExxonMobil's waste processes at the manufacturing sites.

8.6.2 Overview of impacts of no-derogation

In case of a no-derogation scenario, it is expected that the lack of spare parts and replacements for existing installations, along with the inability of ExxonMobil to use fluoropolymer components in their EEA facilities, would potentially result in lower reliability of the processing lines, with potentially significant shorter service lives for the equipment.

This could result in longer downtimes in existing processing lines, with consequent disruption in the output of final refinery products, such as fuels and lubricants, as well as in feedstock for downstream processes.

Refineries are a main pillar of the petrochemical industry, which supplies raw materials and products used widely by downstream sectors professionals (e.g., automotive technicians) and critical transportation fuels. Disruption in its output due to the use of less effective components, or due to the inability to set up new processing lines in the EEA, could eventually lead to insecurity of supply for downstream sectors, who may find themselves relying more on feedstock imported from non-EEA suppliers.

8.7 Summary

Fluoropolymer sealing and lining components are widely used in refineries, as they offer excellent protection of the equipment, and prevent contamination of transported process streams or release of the product to the workplace or the environment. Their performance is a result of the combination of excellent durability in extreme conditions (temperature, pressure, mechanical stress) and their resistance to the corrosive and very reactive chemicals used in refining.

Potential alternative materials are available and in use in some less demanding applications that do not require the same temperature or corrosion / chemical resistance properties. Fluoropolymers are preferred over less expensive alternatives, as they improve reliability of the transport lines and effectively prevent leaks and equipment damage, which can result in accidents or environmental damage, and may pose risks to workers and public health.

If these uses are not covered by a derogation in the PFAS restriction, it will be very difficult, if not impossible, for refinery operators to find suitable replacement parts for the existing lines, as fluoropolymers are the best available material for these applications. In addition, new lines will need to be designed using worse performing materials, which could also potentially increase the risk of unintended releases, failures and, in general, downtime of the process.

As refinery products are essential feedstock for many downstream industries, increased downtime could eventually create insecurity in the supply, with increased reliance of downstream sectors to non-EEA imports.

9. CASE STUDY 3 – PETROCHEMICAL PROCESSING

9.1 Description of use

Downstream petrochemical processes use fluoropolymers in multiple areas, such as lined piping, valves and reactor vessels, seals and gaskets, and coated agitators, low pressure separators, etc.

In a more specific example, components lined with PTFE (e.g., pipes and storage / reaction vessels) are used to transport highly reactive process chemicals, namely sulphuric acid and bromine for the manufacturing of products, such as bromobutyl rubber and methyl ethyl ketone (MEK). Temperatures in these processes range from room temperature to as high as 200 °C, adding significant stress to the equipment.

9.2 Performance requirements

Sulphuric acid is a highly corrosive chemical, which can very quickly corrode unprotected metal, particularly at higher temperatures, such as those used in the bromobutyl rubber and MEK processes.

Similarly, bromine is extremely reactive, particularly in its “wet” phase (with moisture over 30 mg/kg), where it may form hydrogen bromide.

To prevent a release and corrosion of unprotected metal surfaces around the connection points, as well as to prevent exposure of workers to either sulphuric acid or bromine gas, use of linings and appropriate sealing is required.

The importance of the use of fluoropolymer (PVDF) seal to prevent bromine releases is illustrated in a bromine-bromide solution leak report in a French chemical plant in 2015³¹. A 2% bromine-bromide solution leak, resulting in a loss of approximately 57 kg of bromine, occurred due to a faulty stainless-steel flange. The flange had corroded due to a non-bromine compatible material being used. To correct the leak, a solid PVDF plug was installed. To prevent future leaks, the operator installed a level sensor that can be isolated via a PVDF valve on the tank.

Materials used for lining or sealing in bromine and sulphuric acid transport lines must be able to withstand the aggressive chemicals at high temperatures and over prolonged periods. According to the UK Health and Safety Executive (HSE), materials that can be used to line fluorine storage tanks (and pipes) are lead, PVDF, as well as other fluoropolymers, and glass³². However, they point out that, as reactivity is dependent on operating conditions including temperature, pressure and moisture, materials to be used should be tested under expected conditions of use.

When using PTFE-lined equipment in their bromobutyl rubber and MEK process, ExxonMobil complies with the requirements of standards such as ASTM F1545 (equivalent to European standards such as DIN EN 2874) that is crucial to complying with OSHA 1910.119: Process Safety Management for Highly Hazardous Chemicals.

9.3 Assessment of alternatives

The choice of potential materials for use in sulphuric acid and bromine lines is limited, due to the highly reactive nature of the transported chemicals in the high temperature processes.

Non-fluoropolymer materials include lead, glass, zirconium, nickel alloys (Monel, Hastelloy), as well as niobium, tantalum and their alloys. These alternatives are not considered as suitable alternatives in these petrochemical processes for a number of reasons:

- Lead linings, mainly for storage vessels and less commonly for pipes, have been commonly used in the past. However, due to concerns regarding the toxicity of lead, as well as its lower flexibility,

³¹ See: https://www.aria.developpement-durable.gouv.fr/accident/46418_en/?lang=en, accessed on 23 August 2023

³² HSE website – Corrosion / selection of materials. Available online at: <https://www.hse.gov.uk/comah/sragtech/techmeasmaterial.htm>, accessed on 23 August 2023

lead has been replaced by fluoropolymers. In addition, lead is a substance of very high concern and was recommended for inclusion in the REACH Authorisation list in 2022. Moving back to lead-lined vessels and pipes would constitute a regrettable substitution.

- Glass and zirconium linings also lack the flexibility and durability of PVDF in operating conditions. In addition, they need to be measured and cut off-site specifically for each installation, as they cannot be “cut to fit” like fluoropolymer linings. This restricts the design options for the plant operator and also makes any repair or replacement more difficult and time-consuming.
- Nickel alloys, such as Monel and Hastelloy are only suitable for use to transport dry bromine but fail when the moisture content is high.
- Materials such as tantalum and niobium can be used as linings or as pipe material. However, they, too, have lower performance than fluoropolymers (i.e., display corrosion and degrade in presence of corrosive materials) and they also lack the flexibility often required in the process line and also need to be precisely measured and cut off-site. In combination with their very high costs, it makes these materials not suitable alternatives.
- Polymeric materials, such as PEEK and polyphenylene sulphide (PPS), do not have the same temperature and chemical resistance provided by fluoropolymers such as PTFE. The use of those potential alternatives may impact the performance, safety, and reliability of operations of components such as piping and vessels. The performance of non-metallic materials alternatives has not yet been proven, so they carry the potential risk of premature failures and the release of hazardous products to the workplace and the environment.

9.4 Substitution potential

As discussed in the previous section 9.3, there are currently no technically feasible alternatives for the uses of fluoropolymer linings in sulphuric acid and bromine transport lines in ExxonMobil’s bromobutyl rubber and MEK manufacturing processes.

Considering the concern over the use of fluoropolymers, their substitution is under consideration. However, even if a technically and economically feasible alternative were available, substitution in all applications is a process that can take several years.

If an alternative to a fluoropolymer component was available, it could take more than 12 years for it to be introduced in the manufacturing process. The typical steps in this process are:

- Research and refinement of the potential alternative (approx. 6 years)
- Laboratory and qualification testing (approx. 1 year)
- Adoption of alternative into ASTM and ISO standards (approx. 3 years)
- Field testing (approx. 1 year)
- Roll out by replacement of fluoropolymers in existing lines (approx. 1 year)

9.5 No-derogation scenario

The no-derogation scenario, and the expected impacts, need to be examined from two points of view: new installations; and existing ones.

Under a no-derogation scenario, in which it will not be possible to use fluoropolymers in new installations or equipment, it will not be possible for ExxonMobil to set up new processing and transport lines, as it would not be possible to use fluoropolymer lining. In such a case, ExxonMobil may have to use alternative materials, which will lack the durability of fluoropolymers and could impact the process output and shorten the service life of the equipment. It should be noted, however, that ExxonMobil per its Safety Policy is committed to conducting its business in a manner that protects the safety of employees, others involved in its operations, customers and the public and complying with all applicable laws and regulations. In doing so, maintains high quality and safety standards in their

operations, complying with the requirements of applicable industry standards. Therefore, if use of an alternative were to result in non-compliance with specifications, it would not be used and there would be a need to develop a new one.

Similarly, while it will still be possible to continue using fluoropolymers in existing installations, it will not be possible to use fluoropolymer spare parts and replacements. This could result in much shortened service life for piping, and a potential higher risk of release.

As a result and considering the short transitional period of 18 months in the restriction proposal, EEA-located manufacturing facilities will likely cease operations, as it will not be possible to switch to an equally safe and performing alternative as fluoropolymer linings. Production of the important bromobutyl rubber and MEK may have a potential shift to non-EEA locations.

9.6 Assessment of impacts

9.6.1 Assessment of residual risks

Due to the high durability and chemical resistance of fluoropolymers, the sealing components and the linings made out of them do not degrade or erode during their service life. They are also very stable at the high temperatures used in the process, so they do not release any vapours during use. As such, there is very low chance of fluoropolymer emissions during their very long service lives, under normal operating conditions.

At the end-of-life phase, it must be noted that ExxonMobil complies with all applicable laws and regulations regarding the management of their operations and the handling of waste, thereby further reducing the risk of release to the environment. For example, there are certain criteria on specific waste management for certain PFAS compounds within European Union Regulation (EU) 2019/1021 on Persistent Organic Pollutants. There are some Member States who have also implemented additional (either national or regional) requirements for management of PFAS impacted wastes.

If enhanced requirements are needed for management of waste, new requirements would be managed within ExxonMobil's waste processes at the manufacturing sites.

It should be noted that the main risk in a no-derogation scenario may arise from the potential use of materials that have worse durability and performance than fluoropolymers as linings. Lesser performing materials could result in potentially faster corrosion of equipment.

9.6.2 Overview of impacts of no-derogation

In case of a no-derogation scenario, it is expected that the lack of spare parts and replacements for existing installations, along with the inability of ExxonMobil to use fluoropolymer linings in their EEA facilities, would result in lower reliability of the processing lines, with potentially more frequent breakdowns and significantly shorter service lives for the equipment. It must be noted that these products are manufactured in continuous processes, so, any failure could result in significant downtime in existing processing lines, with consequent disruption in the overall output of bromobutyl rubber and MEK. These products are important raw materials for downstream products. If manufacturing output of these products is disrupted, or moved to non-EEA locations, it could create disruption in the downstream supply chain for many important applications in the EEA:

- **Bromobutyl rubber**³³ is used as an inner liner in tyres, to maintain the appropriate inflation pressure, minimising air loss from the tyre and thus reduce rolling resistance and improve fuel efficiency. It is also used as packaging material, to hermetically seal medical devices and pharmaceutical products. Other applications include hoses, windows glazing, engine mounts, train rail pads, protection gloves, inflatable dams, adhesives & sealants, roofing and waterproofing membranes.

³³ ExxonMobil website – Bromobutyl rubber. Available online at: <https://www.exxonmobilchemical.com/en/products/butyl/bromobutyl>, accessed on 23 August 2023

- **MEK³⁴** is mainly used as a solvent in coating, adhesive and ink resins (polyurethane, polyester, acrylic, cellulose, polychloroprene), and for paint stripper formulations. Downstream industries include the healthcare and medical sector, as well as the chemical industry. MEK is a key fluid in formulating polychloroprene adhesives, especially as a replacement for toluene, and is a component of many gravure printing inks.

9.7 Summary

Fluoropolymers, such as PTFE and PVDF are the best available option for pipe and vessel lining when very aggressive chemicals, such as sulphuric acid and bromine, need to be transported. They have very high resistance to those aggressive chemicals at a broad range of temperatures and over long periods. In addition, they enable operators to meet performance and safety specifications arising from national and industry standards.

Alternative materials do not have the same performance as fluoropolymers and they also lack the physical flexibility, as well as the design flexibility offered by fluoropolymers. As a result, use of potential alternatives could result in impaired performance, safety and reliability of the processing lines. In addition, more frequent failures could result in longer downtime of the processing lines and reduced output.

As such, it is very likely that manufacturing processes using fluoropolymers to transport these chemicals (such as bromobutyl rubber and MEK) will move to non-EEA locations, creating uncertainty in the downstream supply chain in the EEA.

³⁴ ExxonMobil website – Methyl ethyl ketone. Available online at: <https://www.exxonmobilchemical.com/en/products/solvents/methyl-ethyl-ketone>, accessed on 23 August 2023

APPENDIX A

API LETTER TO ECHA ON PROPOSED PFAS RESTRICTION

July 31, 2023

European Chemicals Agency (ECHA)
Telakkakatu 6, 00150
Helsinki, Finland

RE: ECHA Annex XV Restriction Report: Per- and Polyfluoroalkyl substances (PFAS)

Dear Sir or Madam:

The American Petroleum Institute (API) respectfully submits the following comments and response to the European Chemicals Agency (ECHA) proposed restriction on per- and polyfluoroalkyl substances (PFAS) published on February 7, 2023. In this letter, API provides general comments on the proposed restriction, and API submits this letter jointly with an analysis of API standards that demonstrates the critical uses of PFAS in the natural gas and oil industry and in international standards and European regulations.

API is the U.S. national trade association representing all facets of the natural gas and oil industry, which supports 9.8 million U.S. jobs and 8% of the U.S. economy and provides critical energy to the European continent. While API represents North American--based companies, API members include multinational corporations with business in Europe and U.S. companies that trade with the European Union (EU), both of which would be significantly affected by the proposed PFAS restriction. API's approximately 600 members include large integrated companies, as well as exploration and production, refining, marketing, pipeline, marine businesses, and service and supply firms.

In addition, API is the global leader in convening subject matter experts across segments to develop, maintain, and distribute consensus standards and safety programs for the natural gas and oil industry. API's goal is to enhance operational safety, environmental protection, and sustainability across the industry, especially through the global adoption of standards. API standards are developed under the American National Standards Institute (ANSI) accredited process, ensuring that the API standards are recognized not only for their technical rigor but also for their third-party accreditation. This accreditation facilitates the incorporation of API standards into regulations by state, federal, and international regulators.

As outlined in this letter, API has significant concerns with aspects of ECHA's proposed PFAS restriction and encourages ECHA to reconsider components of the proposal, including the broad classification of all PFAS, the restriction of fluoropolymers that have not been scientifically shown to be harmful, and the lack of consideration of risk-based approaches. PFAS-containing equipment and materials in the natural gas and oil industry include polymeric seals, gaskets, valves, coatings, lubrication, flexible pipe sheath layers, electrical insulation, and more. These products prevent fugitive emissions, are paramount for the safe handling and transport of petroleum products and chemicals, avert fires, and are key components to large, vital equipment, such as motors, storage tanks, and heat exchangers which help supply affordable energy to society. If promulgated as proposed, this restriction would jeopardize the interests

this restriction aims to protect by creating significant unintended impacts on operational safety, trade, and global supply chains—resulting in fragmented markets, increased emissions, and possible harm to industry personnel and the environment

This letter accompanies an analysis of API standards that reference the direct use of PFAS in equipment and operations. Approximately 55 API standards reference specific PFAS, indicating their essential use in various equipment and materials across all segments of the natural gas and oil industry. While these standards reference PFAS directly, many more API standards require the use of PFAS-containing equipment that must meet certain criteria without mentioning the exact chemical characteristics of the equipment. For example, a standard may require a seal that meets temperature requirements and can withstand corrosive liquids, and while the standard does not strictly mandate the use of a fluoropolymer, polymeric seals are often the only ones that meet the criteria. The attached analysis provides further background on API standards and the role of PFAS therein.

API standards have been referenced more than 1,100 times in international laws, regulations, and national standards, and are referenced in various International Organization for Standardization (ISO) documents. These international references emphasize API standards' role in ensuring safe practices that optimize interoperability and efficiency while safeguarding environmental protection and human health. API's PFAS standards analysis identifies where the EU and Norway reference API and ISO standards in their national and international standards and regulations, underscoring the paramount role of PFAS in European natural gas and oil safety practices.

API appreciates ECHA's proposed 12-year derogation for the petroleum and mining sectors but urges ECHA to grant a permanent derogation for the essential uses of particular PFAS outlined below in all segments of the industry.¹ The use of PFAS-containing equipment and material in the natural gas and oil industry does not have viable alternatives that meet the unique, combined criteria of corrosion resistance, thermal tolerance, durability, excellent sealing properties, lubricity, dielectric strength, and low flammability. The accompanying analysis of API standards further demonstrates these critical uses. API encourages ECHA to justify the reasoning on selecting the specific 6 and 12 years of derogations; if an alternative is not in sight now, a viable alternative will improbably be available within 12 years, if ever. In addition, API requests that ECHA takes a risk-based approach, in lieu of a purely hazard-based approach, for each individual use of PFAS-containing equipment and material. A risk-based approach when assessing each use would identify and prioritize the risks to human health and the environment with the handling of the chemical and determine what is regulatorily required to safely manage those chemicals, which would minimize unintended consequences of a blanket ban.

The ECHA proposal states: "...some PFASs have been documented as toxic and/or bioaccumulative substances, both with respect to human health as well as the environment. Without taking action, their concentrations will continue to increase, and their toxic and polluting effects will be difficult to reverse." API respects ECHA's mandate to protect human health and the environment and shares that mission. However, the majority of PFAS used in the natural gas and oil industry are fluoropolymers that are not water soluble or bioavailable, thus not posing a threat to environmental and human health. Moreover, the use of these fluoropolymers and fluoroelastomers is strictly within industrial operations, and consumers and the broader public do not come into contact with the PFAS-containing equipment that falls under this proposal.

¹ Including, but not limited to, exploration and production, refining, marketing, pipeline, marine transportation, and service and supply firms.

The proposal also utilizes the Organization for Economic Co-operation and Development (OECD) definition of PFAS published in 2021, but the same publication states, “the term ‘PFAS’ is a broad, general, non-specific term, which does not inform whether a compound is harmful or not.”² The umbrella classification of PFAS in the proposal is a misrepresentation that falsely implies all PFAS are harmful, which is not the case. API urges ECHA to reconsider the definition of PFAS to exclude fluoropolymers since they have not been shown to be a threat.

The proposed restriction would compromise the EU’s energy supply and climate neutrality goals and would cause major disruptions to trade, both with energy and fluoropolymer products. PFAS-containing equipment— such as fluoropolymeric seals for cryogenics, fugitive emission valves, centrifugal pumps, pipeline valves—is essential for liquefied natural gas (LNG) storage and transport. These components have no viable alternative and ensure safety by preventing emissions and product loss in LNG handling. In addition, other energy sources, such as photovoltaics and wind energy, use fluoropolymers on solar panels and wind turbines while LNG also plays a role in decreasing greenhouse gas (GHG) emissions. Preventing the use of these essential fluoropolymers would endanger these environmental goals and ultimate reduction of GHG emissions.

Fourteen European countries have LNG import facilities, and European LNG imports reached an all-time high in 2022 (16.5 billion cub feet per day (Bcf/d) on average in April 2022).³ The U.S. (including API members) has become a critical supplier of LNG to Europe as the continent’s demand has soared to compensate for the sharp decline in pipeline imports of natural gas from Russia that preceded its invasion of Ukraine. U.S. LNG exports to the continent increased by 141% in 2022 alone,⁴ and they now represent Europe’s second-largest source of natural gas.⁵ Europe’s ability to import and handle LNG – and accordingly, its energy security – would be significantly diminished if ECHA bans vital fluoropolymers used in facilities, tankers, and operations.

Beyond energy trade disruptions, the proposed restriction would create trade barriers and disrupt supply chains. European fluoropolymers have a high demand that is expected to strongly grow with a projected compounded annual growth rate (CAGR) of 6.5% (if undisrupted by the ban) and currently has a market size of 541.4 million Euros.^{6,7} Key industries beyond the energy sector use these polymers in products and daily operations, including aerospace, electronics, machinery, automotive, medical devices, and more. Germany, France, and Italy are major consumers and Germany is the top producer in Europe. A ban on fluoropolymer products would lead to major supply chain and trade issues with both European manufacturers and consumers being directly affected. Moreover, Europe is a net exporter of fluoropolymers, so the negative economic impact of restricting their manufacturing would reverberate outside of Europe as international fluoropolymer consumers—including API members—would not have access to the specialty equipment that the EU supplies.

² [https://one.oecd.org/document/ENV/CBC/MONO\(2021\)25/En/pdf](https://one.oecd.org/document/ENV/CBC/MONO(2021)25/En/pdf)

³ <https://www.eia.gov/todayinenergy/detail.php?id=52758>

⁴ <https://www.eia.gov/todayinenergy/detail.php?id=55920>

⁵ <https://features.csis.org/us-lng-remapping-energy-security/>

⁶ https://fluoropolymers.plasticseurope.org/application/files/1216/5485/3500/Fluoropolymers_Market_Data_Update_-_Final_report_-_May_2022.pdf

⁷ <https://www.mordorintelligence.com/industry-reports/europe-fluoropolymer-market>

ECHA is already aware of the extreme complications of finding alternatives—if ever possible—for the use of fluoropolymers in the natural gas and oil industry. As Annex E Section 2.15.2.6 of the proposal underscores: “in the case of fluoropolymers, manufactures and suppliers have indicated that it could take a relatively long time (several years to several decades) to transition towards using alternatives that can achieve the same level of performance.”⁸ Furthermore, many of the PFAS products are replacement products and/or components of large, expensive pieces of equipment. Access to spares is imperative to maintain longevity of operations, energy affordability, and safety. If the EU bans these spare products from the market, it will lead to the premature obsolescence of field equipment with costly reverberations for years to come.

API has a strong interest in this proposed restriction on PFAS and recognizes ECHA’s responsibility to safely regulate chemicals to protect the environment and human health. However, as stated with the reasons above, API asks ECHA to consider excluding fluoropolymers from the ban and to take a risk-based approach for other critical PFAS uses. API is actively engaged on issues related to PFAS and understands the complex public policy decisions regulators must make in addressing these chemicals’ effects and environmental presence.

API appreciates the opportunity to provide feedback on ECHA Annex XV Restriction Report: Per- and Polyfluoroalkyl substances (PFAS) and would welcome further dialogue. Please do not hesitate to contact me ([REDACTED]@api.org, [REDACTED]) should you have any questions or comments, or require additional information.

Sincerely,



Alexa Burr
Vice President, Standards & Segment Services
Global Industry Services

⁸ <https://echa.europa.eu/documents/10162/8de11d7c-c56f-e204-5072-e89f11071219>

ATTACHMENT 1 – API Standards: PFAS Analysis

The American Petroleum Institute (API) presents the following analysis on the critical role of per- and polyfluoroalkyl substances (PFAS) throughout the natural gas and oil industry, as well as the chemical industry. There are ongoing [regulatory assessments](#) of per- and polyfluoroalkyl substances (PFAS) in Europe by the European Chemicals Agency (ECHA) which could lead to broad scale restrictions on their manufacture, use, and sales in the EU market, with subsequent impacts on global markets. The United States is the primary supplier of liquefied natural gas (LNG) to the EU, and API members lead the effort to meet the EU's energy demand. As described below, PFAS are essential to LNG distribution and storage, with no viable alternatives that meet all property requirements, and the proposed restriction will compromise the U.S.'s ability to supply this critical energy to Europe. While PFAS producers will be directly impacted, the broader industrial use of these substances across sectors for other energy production, engineering, and chemical manufacturing (among others) purposes is anticipated to be significantly larger, affecting sectors, including chemical producers, pharmaceuticals, textiles, and product manufacturers across the globe.

API Background

Founded in 1919 as a standards developing organization (SDO), API serves as the global leader in convening subject matter experts across all segments of the natural gas and oil industry to establish, maintain, and distribute consensus standards. API is the primary U.S. trade association of the natural gas and oil industry with nearly 600 members involved in all aspects of the industry – exploration and production, midstream transportation, and refining and petrochemicals. Moreover, API develops and maintains more than 800 consensus-based standards to enhance operational safety, environmental protection, and sustainability across the industry, especially through the global adoption of these standards. API is accredited by the American National Standards Institute (ANSI), which ensures API standards are developed in a transparent, consensus-led process. API standards development is an open, balanced process that includes over 10,000 expert volunteers from the public and private sectors, over 2,000 of which are international participants that strengthen the standards' global applicability.

Companies across the globe use API standards, and over 31 markets adopt API standards for usage as national standards or technical regulations by governments to optimize regulatory efficiency and mandate safe industry practices. There are over 670 references to API Standards in the U.S. Code of Federal Regulations (CFR), 3,800 references to API standards in U.S. state regulations, and over 1,100 references by international regulators across 31 markets. Further, international standards organizations, such as the International Organization for Standardization (ISO), along with other global standards developers, incorporate and reference API standards in their documents, which are used in the EU and internationally.

PFAS in API Standards and Oil and Gas Equipment and Operations

The use of PFAS is essential to safe and sustainable global energy and manufacturing operations, as demonstrated by their use in API standards. In oil and gas industrial use, PFAS—especially fluoropolymers and fluoroelastomers—are critical for their high range of temperature tolerance, chemical resistance, low flammability, excellent sealing properties, physical durability, lubricity, high dielectric strength, hydrocarbon fluid containment in the bore of flexible pipes, low friction resistance, and more. API has approximately 55 standards that have specific reference to the use of PFAS as a critical safety element in various uses, including but not limited to:

- Various seals for storage tanks, hoses, valves, and more.

- Gaskets
- Valve seats and packing for various valves, such as ball valves, relief valves, and more.
- PTFE tape for emissions and loss of primary containment (LOPC) avoidance
- Coating of various equipment, such as pipes, bolts, nuts, and more.
- Flanges
- Fugitive emission packing and pump seals
- Electric grid insulation
- O-rings
- Lubrication
- Flexible pipe liner/pressure sheath layers
- Flexible hoses
- Tubes
- Compressors – reciprocating, centrifugal, and liquid ring
- Firefighting foam

API standards are performance-based—requiring or recommending action (including technology and quality certifications, and functional interchangeability) to ensure operational efficiency and safety, rather than being overly prescriptive in all aspects of the equipment and process. This performance-based approach allows standards users to be innovative with their processes and technology as long as they meet the basic safety and functional requirements. However, API standards can have prescriptive components that require certain materials and processes when critical for human or environmental safety and operational integrity. While PFAS is referenced and/or required in approximately 55 API standards, there are many more API standards that mandate PFAS-containing equipment and products without specifically mentioning the chemicals or each component of the equipment (i.e., a standard may require the use of a ball valve, which contains fluoropolymers in the valve seat, but the standard does not mention the many components that make up the valve).

The functional interchangeability of API standards enables the use of spare and sub-parts and products to maintain the longevity and reuse of deployed equipment. The continued market access to these parts and products that contain PFAS (such as seals, gaskets, liners, etc.) are essential to maintaining safe operation and avoiding premature obsolescence of deployed equipment covered in API standards. For example, a polymeric seal is required for an LNG storage tank. If the seal needs to be replaced, it is imperative that there is access to an adequate seal in the market to allow the LNG tank to remain usable.

See **Annex 1** for list of API standards with PFAS references and engineering justifications.

The list above and in **Annex 1** enumerates specific equipment and materials that contain PFAS, and these materials and devices are used ubiquitously throughout industry and are essential components of larger equipment, such as storage tanks (including LNG storage), pipelines, heat exchangers, motors and rotary equipment, heaters, depressurizing systems, and more.

For example, gaskets and seals are essential in the natural gas and oil industry by creating a tight and reliable seal between two pieces of equipment, such as valves, pipelines, flanges, pumps. These seals prevent leakage of liquids and gases, which is essential for safety, operational efficiency, and environmental protection. It is paramount that these gaskets and seals have extreme temperature tolerance (high and low), resistance to corrosive material, flexibility, strong durability, and pressure

resistance, all criteria that cannot be met without the use of fluorinated polymers and elastomers. More details on the essential role of other PFAS-containing equipment are included in **Annex 1**.

PFAS in Environmental Safety and Emissions Reduction

The sealing properties of the polymers and elastomers prevent environmental disasters and play a key role in the reduction of greenhouse gas emissions. The use of polymers to seal pipelines, storage tanks, and valves support the safe transport and handling of critical substances that could cause potential safety risks, environmental contamination, and loss of resources if the seals did not meet necessary properties that PFAS provide.

The demand for natural gas is growing exponentially in Europe and provides approximately 25% of the EU's energy supply, according to the European Commission⁹. In addition, the EU includes liquefied natural gas as a key tenet in the EU Energy Union Strategy, enhances energy security in a time of scarcity and war, and significantly reduces greenhouse gas emissions. Polymeric seals and gaskets are essential for the handling and transportation of LNG for storage tanks and pipeline transportation. These PFAS-containing seals tolerate the low temperatures (-162° C) for liquifying natural gas and help prevent fugitive emissions.

In addition, a majority of PFAS used in the natural gas and oil industry are fluoropolymers (PTFE, PVDF, FKM/FKKM) and fall under the category of polymers of low concern (PLC), as defined by the Organization for Economic Co-operation and Development (OECD).¹⁰ A recent study published in *Integrated Environmental Assessment and Management*, a scientific journal, demonstrates that PVDF, FKM/FKKM, and other fluoropolymers meet the criteria of PLC.¹¹ The study does not address PTFE, but PTFE has also been confirmed to meet the PLC criteria, as shown in Table 2 of a separate article in the same journal.¹²

The proposed ban aligns with the OECD definition of PFAS, but the OECD report that defines PFAS, [*Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance \(2021\)*](#) also states, “the term ‘PFAS’ is a broad, general, non-specific term, which does not inform whether a compound is harmful or not.” The fluoropolymers referenced in API standards and used in the natural gas and oil industry have been shown not to pose a threat to human or environmental health, as evinced by these studies and OECD PLC criteria and PFAS definition.

European Use and Reference of API Standards

At least 20 references to standards containing specific mentions of PFAS were identified in the policies, regulations, and guidance issued by relevant bodies in eight European states (see Table 1 below). As standards usage in most cases is voluntary and/or company-specific, this severely understates the usage rate of these API standards—but is intended to demonstrate how API standards utilizing PFAS are crucial to regulatory requirements for health and environmental safety in Europe. When standards are incorporated into policies and regulations, they become mandatory in order to meet a regulatory objective. The list below underscores the importance and reliance on API standards to protect human health and the environment across the EU and Norway.

⁹ https://energy.ec.europa.eu/topics/oil-gas-and-coal/liquefied-natural-gas_en

¹⁰ OECD Criteria for Polymers of Low Concern (PLC): <https://www.oecd.org/env/ehs/risk-assessment/42081261.pdf>

¹¹ <https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/ieam.4646>

¹² <https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4035#:~:text=We%20will%20show%20that%20fluoropolymers,human%20health%20and%20the%20environment.>

Table 1: Examples of References of API Standards in EU and Norwegian National Policies

Denmark	<i>Guidelines for Drilling</i>	API 13B-1, Field Testing Water-based Drilling Fluids
Germany	<i>BVEG Guidelines: Well Integrity Guidelines (7/2021)</i>	API 6A, Wellhead and Tree Equipment
	<i>BVEG Well Control: Drilling, Workover, Well Intervention (9/2015)</i>	API 16A, Specification for Drill-through Equipment
	<i>Announcement of the Technical Rule for Long-Distance pipelines according to § 9 Paragraph 5 of the Pipeline Ordinance</i>	API standards for flanges, gaskets, bolts and nuts (including API 608, 600, 594, 623, 609, 526, 599; gaskets, bolt, and nuts are universal in O&G equipment in all segments.)
Greece	<i>Presidential Decree #64, Implementation of the Regulation for the Safe Refueling of Ships with Liquefied Natural Gas as Fuel (June 20, 2019)</i>	API 520-1, Sizing, Selection, and Installation of Pressure-relieving Devices, Part I—Sizing and Selection
		API 520-2, Sizing, Selection, and Installation of Pressure-relieving Devices, Part II—Installation
Italy	<i>Directorial Decree of 29 November 2004, Safety Requirements for Special Type Installations in Drilling Activities</i>	API 16A, Specification for Drill-through Equipment
Netherlands	<i>Mining Regulation of the Netherlands, January 2003</i>	API 17B, Recommended Practice for Flexible Pipe
		API 17J, Specification for Unbonded Flexible Pipe
Norway	<i>Guidelines regarding the Technical and Operation Regulations (2020)</i>	API 520-1, Sizing, Selection, and Installation of Pressure-relieving Devices, Part I—Sizing and Selection
		API 520-2, Sizing, Selection, and Installation of Pressure-relieving Devices, Part II—Installation
	<i>Guidelines regarding Facilities Regulations (2020)</i>	API 520-1, Sizing, Selection, and Installation of Pressure-relieving Devices, Part I—Sizing and Selection
		API 520-2, Sizing, Selection, and Installation of Pressure-relieving Devices, Part II—Installation
		API 17J, Specification for Unbonded Flexible Pipe, Recommended Practice for Flexible Pipe
	<i>Guidelines regarding the Activities Regulations (2020)</i>	API 17B, Flexible Pipe

Portugal	<u>Ministry of Economy, Innovation, and Development, Ordinance No. 137/2011</u>	API 520-1, Sizing, Selection, and Installation of Pressure-relieving Devices, Part I—Sizing and Selection
	<i>Summary: Adopts, as Regulation of the Terminal for Reception, Storage and Regasification of Liquefied Natural Gas (LNG), the NP EN 1473 standard, “Installation and equipment for liquefied natural gas - Design of onshore installations”</i>	API 520-2, Sizing, Selection, and Installation of Pressure-relieving Devices, Part II—Installation
	<u>Ministry of Economy, Ordinance No. 670/2001</u>	API 520-1, Sizing, Selection, and Installation of Pressure-relieving Devices, Part I—Sizing and Selection
	<i>Summary: Adopts, as the Technical Regulation Relating to the Design, Construction, Operation and Maintenance of the Terminal, the EN 1473 standard.</i>	API 520-2, Sizing, Selection, and Installation of Pressure-relieving Devices, Part II—Installation
Spain	<i>Resolution of May 7, 2012, of the Secretariat of State for the Environment, which formulates Environmental Impact Declaration of the Development of the Montanazo and Lubina fields, Tarragona</i>	API standards pertaining to pipelines (API 17B, API 17J, API 15S)

*Note: this table is not all inclusive of European policies that reference API standards.

ISO Standards Utilizing PFAS

International Organization for Standardization (ISO) standards are widely used across Europe and incorporate PFAS as an essential element in the standards. API works to harmonize its standards with ISO standards, and conversely, ISO standards reference API standards and publications that require PFAS.

The 16 ISO standards below directly reference PFAS, as shown below. As noted above with API standards, many more ISO standards require the use of PFAS-containing equipment but do not directly reference the chemical:

- *ISO 12086, Plastics — Fluoropolymer dispersions and moulding and extrusion materials — Part 1: Designation system and basis for specifications*
- *ISO 23936, Oil and gas industries including lower carbon energy — Non-metallic materials in contact with media related to oil and gas production — Part 1: Thermoplastics*
- *ISO 10684, Fasteners — Hot dip galvanized coatings*
- *ISO 1629, Rubber and latices — Nomenclature*
- *ISO 16961 Internal coating and lining of steel storage tanks*
- *ISO 31800 Energy independent, prefabricates, community-scale, resource recovery units*
- *ISO 17782 Scheme for conformity assessment of manufacturers of special materials*
- *ISO 23936-2 Non-metallic materials in contact with media relation to oil and gas production – Part 2: Elastomers*

- *ISO 10423 Drilling and production equipment*
- *ISO 13628 Design and operation of subsea production system – Parts 3, 10, and 15*
- *ISO 10400 Formulae and calculations for the properties of casing, tubing, drill pipe, and line pipe used as casing or tubing*
- *ISO 11960 Steel pipes for use as casing or tubing for wells*
- *ISO 13678 Evaluation and testing of thread compounds for use with casing, tubing, line pipe and drill stem elements*
- *ISO 15463 Field inspection of new casing, tubing, and plain-end drill pipe*
- *ISO 27914 Carbon dioxide capture, transportation, and geological storage – Geological Storage*
- *ISO 27916 Carbon dioxide capture, transportation, and geological storage – Carbon dioxide storage using enhanced oil recovery*

Of these standards, 11 of the 16 above (excluding ISO 31800, ISO 27914, ISO 27916, ISO 1629, and ISO 12086) have been adopted directly by the European Committee for Standardization (CEN) as regional European Standards (EN), making them critical for European safety, manufacturing, trade, and industry operations. As a result, EU member states have adopted some or all these as national standards by their respective national standards bodies.

Additionally, ISO 12086 has been adopted as a national standard by:

- Austria
- France
- Italy
- Netherlands

European states and the EU also reference ISO standards in national policy and regulations. **Table 2** below shows some examples:

Table 2: Examples of ISO Standards Referenced in European Policy Measures

Country	Policy Measure	ISO Reference
European Union	<i>Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives</i>	ISO 27914
Germany	<i>WirtschaftsverbandErdöl- und Erdgasgewinnung e.V (WEG) Best Practice: Hydraulic Fracturing in Conventional Reservoir Rocks*</i>	ISO 11960 ISO 10400

	<i>Wirtschaftsverband Erdöl- und Erdgasgewinnung e.V. Technical Rule: Casing Calculation*</i>	ISO 11960 ISO 10400
France	<i>Legal Journal of France</i>	ISO 11960 ISO 10423 ISO 13678 ISO 15463
Norway	Petroleum Activities Regulations Guidelines	ISO 10423
	Petroleum Facilities Regulations Guidelines	ISO 10423 ISO 13628
	CO2 Safety Regulations Guidelines	ISO 27914

* *WirtschaftsverbandErdöl- und Erdgasgewinnung e.V* (Economic Association for Oil and Gas Production) is the national upstream oil and gas industry association for Germany. While German regulators do not issue them, regulators endorse their use, and industry operators follow them.

ISO standards are prominent in Europe, and as shown above, they are often mandated by regulation or encouraged to be used at the national and international level in Europe, including in all five countries that proposed the PFAS restriction. ISO standards are developed by international experts and approved by an international body that sets the basic safety and operational requirements. ISO standards establish a common framework for consistency, compatibility, and interoperability of industry equipment, processes, and regulations and are used by industry to streamline supply chains within and outside of the EU. If the ECHA proposal is passed, it would prevent compliance with these ISO standards where required, which could in turn, disrupt oil and gas operations throughout the continent and upend supply chains.

NATO Standards

Both API and ISO standards have a critical role in European regional security. The North Atlantic Treaty Organization (NATO) utilizes standards for military equipment and procedures for NATO members, and NATO standards often reference and mandate the use of civilian standards, including both API and ISO standards. NATO standards are classified, and therefore API cannot share further details. However, it is confirmed that API standards are referenced in NATO standards, and over 440 ISO standards are referenced in NATO standards.

Conclusion

API's analysis of API and ISO standards underscores the crucial role of PFAS in the natural gas and oil, chemical, and broader manufacturing industries, which supply the European continent with necessary energy in a time of scarcity. API appreciates the 13.5-year derogation in the proposal for the natural gas and oil, but if the proposed ban is passed as is, it will affect approximately all 600 API members integrated in all segments of the natural gas and oil industry, as well as have significant impacts on broader manufacturing industries. The risk of PFAS restriction in other industry sectors that may negatively impact the natural gas and oil sector should be carefully evaluated. The proposed ban would create impediments to industry operators and manufacturers that provide safe, reliable energy to the European continent and would present challenges to achieving carbon neutrality and greenhouse gas reduction goals.

Annex 1 – PFAS References in API Standards

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	551	Process Measurement	2	Refinery instruments use seals made of FFKM; Fluorinated polymers are required for installing oxygen instruments informative on fluoroelastomer temp limitations and material codes; references the use of fluoropolymer covers for horn antennas; PVDF: "the probe is insulated with a material with a high resistivity, e.g. PVDF, TFE, or a ceramic. PVDF maximizes the capacitance.	3.6.4; 7.3.8.3; 7.3.6.3	Trade names and material codes for materials are required and must comply with the relevant standards; long list of PFAS-containing materials included (3.6.3); an insulated probe is required as part of RF capacitance/admittance level transmitters when measuring conductive liquids; PVDF is recommended to maximize the capacitance. Refinery instruments rely on o-rings and special gasket to seal their components; FFKM is a preferred seal material because it has a higher operable temp (600F) and some grades are resistant to steam; For oxygen instrument installations, there is a high fire hazard and fluorinated polymers are required as opposed to other polymers because of their fire resistance and good lubricant performance, which decreases the risk of incident.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	553	Refinery Valves and Accessories for Control and Safety Instrumented Systems	2	4.22 Bonnet gaskets should be fully retained spiral wound with PTFE Explains the importance of PTFE for lubricating properties and how it is the most common valve packing material; 4.2.4 Fugitive Emissions: "FFKM (perfluoroelastomer) has excellent inertness and good lubricating properties"	4.22 and throughout informatively covering valve spec packing; 4.2.4: FFKM for fugitive emissions	Fluoropolymers and fluoroelastomers are critical and essential for the gasket and valve industries and safety in the oil and gas industries. PTFE, FFKM, and other PFAS-containing materials are used in these applications for optimal sealing and thermal and chemical tolerance that prevents fugitive emissions that compromise safety and harm the environment.	
Downstream	574	Inspection Practices for Piping System Components	4	Optional inspection to perform electrical conductivity test on fluoropolymer tube hose	10.5 Flexible Hoses	Fluoropolymer tubing withstands corrosive materials that react with metal tubing and is comprised of a chemically inert composition; fluoropolymers used for flexible tube hoses and tested to ensure electrical continuity;	
Downstream	584	Integrity Operating Windows	2	7.4 "temperatures higher than 300F will cause permanent damage to PTFE brushing that insulate the electric grids"	7.4	The PTFE insulation material for electric grids allows them to operate in harsh environments due to the material's high dielectric strength, resistance, flexibility, and excellent thermal and electrical properties. On the insulation of electric grids it cannot exceed 300F.	
Downstream	588	RP for Source Inspection and Quality Surveillance of Fixed Equipment	1	13.3.10 "generally the spiral wound gasket has a metal alloy wound outwards in a circular spiral with a filler material (PTFE);	13.3.10 informatively	spiral round gaskets are made of a metallic strip with a filler material. PTFE is often used as the filler material for optimal salability, inherent resiliency, and gasket blowout resistance.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	608	Metal Ball Valves- Flanges, Threaded, and Welding Ends	5	4.3.1 Seat Rating for PTFE and R-PTFE: valves employing PTFE or modified PTFE seats and valves...shall have pressure-temperature ratings equal or higher than the values shown in Table 1 and 2; normative by requiring rating for the PTFE valves	4.3.1; 4.3.2; Table 1 and 2	the ball valve industry for petroleum and petrochem could not exist without PTFE, which is used in the lining, seats, and packing. The valves contain an upstream and downstream seat that keep liquids or gases from escaping. PTFE is the material used for seating because of its flexible, extreme durability, chemical resistance, and high temperature range, all which support safety when dealing with hazardous materials. It is required to select the pressure and temperature ranges with the tables in API 608. PTFE, FKM, and other fluoropolymers are used for packing with ball valves (see 662 and 553), which prevents fugitive emissions.	
Downstream	609	Butterfly Valves	9	Same info as in 608 (4.3.1); normative by requiring rating for the PTFE valves	4.3.1	Same justification applies to butterfly valves as it does to ball valves (API 608) (and other types of valves)	
Downstream	610	Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries	12	Perfluoroalkoxy (PFA) in Table H.3 (nonmetallic wear part materials); PTFE - coating requirements	Annex H (normative annex) for PFA; PTFE - 7.6.1.7; requires PTFE or another material acceptable to purchaser; included in table H.1.	Specifies PTFE coating requirements for equipment, which is a preferred coating material.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	621	Reconditioning of Metallic Gate, Globe, and Check Valves	5	Figure B.4: PTFE V-ring Packing Arrangement; informative info on gasket types with PTFE throughout	Figure B.4 in normative annex	PTFE is used for valve packing due to its resilience and excellent sealing properties. Packing in valves stops leakage between the stuffing box and the stems, thus preventing fugitive emissions that compromise safety and are environmentally injurious.	
Downstream	622	Type Testing of Process Valve Packing for Fugitive Emissions	2	PTFE Content Determination in Lubricant	6.3.1	PTFE is used in lubricants due to its low coefficient of friction (higher lubricity); PTFE is used for valve packing due to its resilience and excellent sealing properties. Packing in valves stops leakage between the stuffing box and the stems, thus preventing fugitive emissions that compromise safety and are environmentally injurious.	
Downstream	650	Welded Tanks for Oil Storage	13	Informative table for guidance on seal material for fluid stores (crude oil, refined products, gasoline): each includes fluoropolymers and/or fluoroelastomers as a guidance (along with other materials))	H.4.4.2	PFAS are essential in seals for tanks for oil storage and LNG storage (which requires cryogenic temperatures that fluoropolymers and fluoroelastomers can withstand); the fluoropolymer and fluoroelastomeric has high thermal and chemical resistance required for sealing storage tanks.	ISO 16961: 2015; ISO/DIS 16961; ISO 31800:2020;
Downstream	660	Shell and Tube Heat Exchangers		use of PTFE as a filler material in gaskets	Table 3	Table 3 outlines Assembly Gasket Stress, which is based on the use of facing layers or filler materials (such as PTFE). PTFE is often used as the filler material for optimal sealability, inherent resiliency, and gasket blowout resistance. Gasket stresses are required to comply with the table...	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	661	Air-cooled Heat Exchangers	7	7.2.10.10: the exposure temperature shall not exceed 150 C for PTFE base composite bearing material 8.4.2: louver bearings shall be of either PTFE base materialor an approved alternative	7.2.10.10 and 8.4.2	Louver bearings use PTFE to withstand the high temperatures for the heat exchangers.	
Downstream	664	Spiral Plate Heat Exchangers	1	7.8.1: gasket cover sheet material shall be non-asbestos compressed fiber, PTFE, graphite, or equal; this is determined by the user for which option best fits their needs.	7.8.1	The only non-metallic components of these exchangers are the gaskets made up of PTFE and FKM for its resistance and resiliency.	
Downstream	667	Plate-and-Frame Heat Exchangers	1	Standard gives requirements and recommendations for the mechanical design, materials selection, fabrication, inspection, testing, and preparation of gasketed plate heat exchangers. The standard gaskets for these units are elastomeric, where fluoropolymers, FKM, FKKM, and similar materials are used		Fluoropolymer and fluoroelastomers are required in the gasket industry, especially with gasketed plate heat exchangers, due to its for optimal sealability, inherent resiliency to chemicals, high range of temperature tolerance, and gasket blowout resistance.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	670	Machinery Protection Systems	5	C.3 (normative annex): Cable material limits shall be considered. For example, PTFE-insulated cables cannot normally be used above 200C; mention of elastomeric material for sealing (6.2.4.6)	C.3	Fluoroelastomers used for sealing and PTFE-insulated cables used without as long as it is below 200C (approx. 400C). It is often the preferred material and has higher temperature tolerance than other materials.	
Downstream	675	Positive Displacement Pumps	3	references ASTM standards for FKM and FFKM (ASTM D1418)	Annex B	ASTM D1418 is the standard practices for rubber and rubber latices--Nomenclature; this document classifies and codes rubbers according to chemical composition of the polymer chain	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	682	Pumps-shaft sealing systems for centrifugal and rotary pumps	4	6.1.1.10 "o-ring grooves shall be sized to accommodate perfluoroelastomer (FFKM) O-rings (includes important note under this requirement) 6.1.6.5.2: requires the use of FFKM for secondary seals O-rings. B.3.3.2.3 FFKM has a PTFE polymer base and is not typed like FKM. The chemical inertness of the full fluorinated backbone allows excellent resistance to acids and bases, oxidizers, water and hydrocarbons. Special FFKM compound are required for amine and steam service Seal Selection Guide (annex A) recommends families FKM and FFKM based on successful user experience Many PFAS throughout this doc (PTFE, FKM, FFKM). Mostly recommends FFKM throughout doc.	6.1.1.10; B.3.3.2.3, Annex A recommends FFKM throughout	O-rings are comprised of FKM, FFKM, PTFE, or other fluoroelastomeric and fluoropolymeric materials due to the sealing properties, chemical inertness, thermal resistance, etc.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	692	Dry Gas Sealing Systems for Axial Centrifugal, Rotary Screw Compressors, and Expanders	1	6.8.3 Abradable Seals contain PTFE in the stationary component of the seal; underscores use of PTFE as polymer seal throughout the standard	6.10; F.3.1; 6.8.3; H.6.2	Fluoropolymers used for dry gas seals due to its resiliency against gas and chemicals; used in stationary component of abradable seals for durability against the rotating labyrinth teeth.	
Downstream	939-D	Stress Corrosion Cracking of Carbon Steel in Fuel-Grade Ethanol	2 A1	"[API report 1132] showed that most companies increase their usage of FKM and PTFE for elastomer parts subjected to static sealing and dynamic sealing while in contact with gasoline containing oxygenates"	Informative and referencing API Report 1132	FKM and PTFE selected due to their chemical and fire resistance, which is a major hazard with gasoline containing oxygenates (additive).	
Downstream	2001	RP on Fire Protection in Refineries	10	informative: use of AFFF as fire fighting foam		Aqueous film forming foam (AFFF) is made from PFAS and is highly effective for fighting hazardous flammable liquid fires, such as oil and gasoline.	
Downstream	2021	Management of Atmospheric Storage Tank Fires	4	Details PFAS-containing firefighting foam (AFFF) and SFFF; currently under revision		Aqueous film forming foam (AFFF) is made from PFAS and is highly effective for fighting hazardous flammable liquid fires, such as oil and gasoline; Synthetic Fluorine Free Foams (SFFF) do not contain PFAS	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Downstream	12B	Specification for Bolted Tanks for Storage of Production Liquids	17	4.8.1: "the head of the bolt shall be encapsulated with PVDF, ABS, or polyester, and a sealing ring shall be molded under the head of the bolt 4.8.2" nuts in contact with stored liquid shall be protected with threaded PVDF nut caps"	4.8.1; 4.8.2	PFAS coating required for resiliency and fluoropolymeric seals required for its excellent resiliency and sealing qualities.	ISO 27916:2019
Downstream	520-1	Sizing, Selection, and Installation of Pressure-relieving Devices Part 1	9	Includes mentions of fluoroelastomers in the Table D.1 - Instructions for Spring-loaded PRV Specification Sheet	Table D.1	Fluoroelastomeric and fluoropolymeric materials used in pressure-relief valve manufacture specification for its excellent sealing properties, which optimizes operational safety.	
Downstream	520-2	Sizing, Selection, and Installation of Pressure-relieving Devices	7	states fluoropolymers gaskets are suitable	A.3 Gasket Selection	Fluoropolymer gaskets are used for its resistance to chemical abrasion, heat resistance, insulation, and more, which is ideal for high pressure devices.	
Midstream	14.1	MPMS Chapter 14 Section 1	7	11.5 "floating Piston cylinders should have the following features....PTFE seals or equivalent"	11.5	PTFE used for durable and excellent sealing properties.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	1PER15K-1	Protocol for Verification and Validation of High-pressure High-temperature Equipment	1	PTFE (Teflon), RYTON, perfluoroelastomer, fluoroelastomers, and more are detailed throughout the doc for elastomeric seals, general nonmetallic seal properties, mechanical properties, and temperature resistant properties. Document also details the effects of gas, chemicals, heat, and more on elastomers. 6.1.7.8 qualification of seals and manufacturers Table 7 and 8	entire document	PTFE and other fluoropolymers and fluoroelastomers used for the sealing to ensure impermeability, chemical resistance, thermal resilience, etc.	
Upstream	11S4	RP for Sizing and Selection of Electrical Submersible Pump Installations	1	Includes max. service temps for fluoroelastomers and TFE/P (partially fluorinated polymer);	8.2.1	Standards includes considerations for seal selection, and operating temperature is a point for consideration. Maximum service temperatures for multiple elastomers included; Fluoroelastomer compounds have highest heat resistance	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	11S5	RP for the Application of Electrical Submersible Cable Systems	1	Definitions section includes many references to PFAs- fluoropolymers, PVF, ECTFE, PVDF. However, not directly mentioned in the body, but the doc is short and the definitions are used as background on the RP for application.	Definitions	PFAS, especially fluoropolymers) used in electrical submersible cable systems for the material's high dielectric strength, chemical and liquid resistance, flexibility, and excellent thermal properties.	
Upstream	11S7	RP for Application and Testing of Submersible Pump Seal Chamber Section	1	Includes max. service temps for fluoroelastomers and TFE/P (partially fluorinated polymer);		Standard includes considerations for seal selection, and operating temperature is a point for consideration. Maximum service temperatures for multiple elastomers included; Fluoroelastomer compounds have highest heat resistance	
Upstream	13B-1	Field Testing Water-based Drilling Fluids	5	A.5.2.6 in Normative Annex: requires the use of stopcock valve that are made of PTFE components in testing drilling fluids.	A.5.2.6 and throughout	Stopcock valve is required to test for soluble carbonates in a drilling fluid system; the stopcock requires PTFE material for sealing and corrosion resistance.;	ISO 13501:2011 ISO 10416:2008 (2003 version of 13B-1) ISO 11961:2018 ISO 10414-1:2008

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	13k	RP for Chemical Analysis of Barite	4	6.4 Sample preparation and testing requires PTFE acid digestion vessel, cells, plug, and stirring rod; includes the required step-by-step use of PTFE in the procedures for the chemical analysis	6.4 and throughout	PTFE acid digestion vessel, plug, cells, and stirring rod required for chemical testing because of its extreme chemical resistance properties that makes the testing possible.	
Upstream	13I	Lab Testing of Drilling Fluids	9	recommends use of PTFE inserts and liners throughout	14.3.4.5, 14.3.7; 15.2.2; 15.3.2.4:	PTFE inserts, stirrers, and liners used throughout in the testing equipment for its durability when interacting with testing substances.	
Upstream	14G	RP for Fire Prevention and Control on Fixed Open-type Offshore Production Platforms	4	"examples of active fire protection systems would be fire water, AFFF, CO, or dry chemical systems"	9.1	Aqueous film forming foam (AFFF) is made from PFAS and is highly effective for fighting hazardous flammable liquid fires, such as oil and gasoline	
Upstream	15CLT	RP for Composite Lined Steel Tubular Goods	1	PTFE in corrosion barrier (CB) ring manufacture; shall be determined by ASTM D4745; mentions that CB rings are made from PTFE	6.2; 4.2; throughout	Corrosion barrier rings are filled with PTFE for thermal resistance and physical resilience. They are required to be specified according to ASTM D4745 - Standard Classification System and Basis for Specification for Filled PTFE Molding and Extrusion materials	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	16A	Specification for Drill-through Equipment	4	Fluoroelastomer (Viton) requires fluoroelastomer compound marking code when used for nonmetallic components, such as seals and ring gaskets; the marking required for the material must comply with ASTM D1418. Provides temperature ratings and requirements for nonmetallic seals.	table 4 table 43	If FKM is used as the nonmetallic seal or gasket, it must be marked as per ASTM D1418. Its use is determined by the experts based on specific criteria needed for the drilling equipment. It is often used in applications that require high tolerance for a wide range of chemicals and temperatures. Table 4 provides temperature ratings and requirements for nonmetallic seals (i.e. fluoropolymers). In addition, coatings that contain PTFE, PFA and FEP (e.g., Xylan) may be used by many OEMs to provide a low friction, corrosion resistant coating on parts inside and outside the pressure containing assemblies. They are typically applied by spraying or brushing and then baked.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	17B	RP for Flexible Pipe	5	This document focuses heavily on the use of Polyvinylidene Fluoride (PVDF) throughout the entire doc, mostly focused on PVDF layers in piping (PVDF-based pipes); Fluoropolymer coatings referenced in sections addressing corrosion-resistant coatings for end fittings, they are commonly used for end fittings	Throughout the entire document, including annexes tailored to just PVDF; Fluoropolymers coating references for end fittings (6.2.5 and 6.3.4)	PVDF is used in piping for resiliency, chemical resistance, thermal tolerance, and flexibility.	
Upstream	17D	Specification for Subsea Wellhead and Tree Equipment	3	"adherent coatings, such as PTFE... are acceptable on the flange working surfaces"	Annex F	The coating is used for its high temperature properties, a low coefficient of friction, and chemical and abrasion resistance. Some fluoropolymer coatings can reach up to 500F.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	17F	Standard for Subsea Production Control Systems	4	Annex C: qualification test of control fluids: "select aging vessels that are of 316 or better quality stainless steel for wetted components. An inner lining of PTFE is recommended" C.11: "cervices shall be formed by PTFE washers...and PTFE O-rings"; included informatively throughout the annex and document; Includes info on fluoroelastomer compatibility	Annex C	Fluoroelastomer seals are essential for subsea exploration and production and well equipment for sealing properties, resistance to corrosive material, and resiliency with sour oil and gas. The fluoroelastomeric high temperature tolerance is required in these operations.	
Upstream	17TR1	Evaluation Std for Internal Pressure Sheath Polymers for High Temperature Flexible Pipes	1	Highly technical informative details about PVDF properties as part of internal pressure sheath for high temp. flexible pipes throughout Annex A and F and mentioned in section 7; many mentions of polymers for high temp. flexible pipes throughout	Annex A, Annex F, and 7.3.3	PVDF used in piping (especially flexible piping) for resiliency, chemical resistance, thermal tolerance, flexibility, and pressure tolerance.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	17TR8	High-pressure High-Temperature Design Guidelines	2 A1	Elastomeric seals and nonmetallic seals mentioned throughout: B.5: elastomer seal system is likely to contain a mixture of metallic materials for packing retainers....it is important to ensure that elastomer sealing configurations provide equivalent sealing protection to the metallic sealing protection systems.	B.5 and seals/elastomeric seals mentioned throughout	Fluoroelastomeric seals used as non-metal sealing for its strong chemical resistance, sealing properties, thermal properties, and durability.	
Upstream	17J	Specification for Unbonded Flexible Pipe	4 A1	Table 8-Flexible Pipe Layer Design Criteria: gives max. allowable bending strain for PVDF in static applications and for storage in dynamic applications. "for quasi-dynamic and dynamic-supported applications, higher maximum bending strain shall be allowed for PVDF, if validated by testing	Table 8; 5.3.2.1.5	PVDF used in piping (especially flexible piping) for resiliency, chemical resistance, thermal tolerance, and flexibility; however, bending strain max. allowance must be taken into consideration when using in operations.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	19D	Measuring Conductivity of Proppants	2	6.1.2 Sealing Rings: "testing at all temperatures shall use rings made of higher temperature fluoro-rubber (FKM), such as Viton (trademark name)	6.1.2	FKM and fluoroelastomers required for high temperatures because of its high temp. tolerance	
Upstream	20G	Welding Services for Equipment Used in Petroleum and Natural Gas Industry		Informative checklist in Annex A, Weld Supplier Audit Process. PTFE related question asks if tubes are made of PTFE or other suitable material for gas; while informative and in a checklist, the question underscores that PTFE is a good material for gas lines and tubes to avoid leakage or avoid use of poor quality/porous material	A.8	PTFE used in tubing and gas lines for chemical resilience, corrosion and heat resistance, sealing properties, and overall durability while maintaining flexibility.	

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	21TR1	Materials Selection for Bolting	E2 A2	Fluoropolymer: 4.6.4 reference of fluoropolymer as the typical topcoat for lubricity required for uniform torque. Use of FP as nonmetallic coatings for a combination of corrosion resistance, wear resistance, and lubricity. PTFE: 4.6.3: typical coatings and plating used in oil and gas industry includes PTFE-based coating; specifies lubricity of PTFE coating.	4.6.4; 4.6.3	The coating is used for its high temperature properties, a low coefficient of friction, and chemical and abrasion resistance. Some fluoropolymer coatings can reach up to 500F, and it is a choice for bolting.	
Upstream	2RD	Dynamic Riser for Floating Production Systems	2	7.10.3 any coating of bolts shall be selected with due considerations of how such coatings affect stud tensioning. "NOTE: ptfe coating have low friction coefficient and the torque has to be applied accordingly"	7.10.3	As stated, PTFE is often used for bolt coatings due to its resilience and lubricity. Lubricity needs to be taken into account when using the bolts with PTFE coating due to its slickness.	
Upstream	5C1	RP for Care and Use of Casing and Tubing	18	both sections state "when making up round-thread connections with PTFE rings, 70 percent of the listed values are recommended"	4.3.4 and 5.3.1		ISO/TR 10400:2018 ISO 11960:2020 ISO 13678:2010

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	5C5	Procedures for Testing Casing and Tubing Connections	4	5.7.5.4: Ported Box Leak Trap Device. "Assemble the ported box in the following manner: c) install threaded fitting into holes using thread sealer, such as PTFE"	5.7.5.4	Preferred sealing due to its excellent sealing properties and resistant to temp, chemicals, and other elements.	ISO/TR 10400:2018 ISO 13678:2010
Upstream	5CT	Case and Tubing	10	K.8.2 "rings shall be made from virgin PTFE...the starting PTFE shall be free of filler"	Annex K	Virgin grade PTFE is recommended for these O-rings/seal ring couplings for tubing because it is purer (no fillers), thus giving it better resistance and sealing properties.	ISO 27914:2017 (2011 version of 5ct) ISO/TR 10400:2018 ISO 11960:2020 ISO 15463:2003 ISO 13678:2010
Upstream	6A	Spec for Wellhead and Tree Equipment	21 A2	Informative "a coefficient of friction of 0.07 approximates threads and nut face coated with fluoropolymer material Table K.5 specifies seals for top connector plugs for H2S service (FKM)	Annex H (informative)	O-ring sizes determined by pressure and nominal size for hydrogen sulfide; FKM is the go to material for O-ring due to its excellent sealing properties and is required for hydrogen sulfide sealing due to its chemical resistance to gas. A coefficient of friction is the measure of lubricity for lubrication, and the low coefficient for fluoropolymers makes it an ideal additive to lubrication. The use of fluoropolymer lubricant (such as PTFE) is commonly used and needed for nuts and bolts for its durability and resistance to elements.	ISO 27914:2017 ISO 13628-15:2011 ISO 13628-10:2005 ISO 27916:2019 ISO 17782:2018 ISO 13628-6:2006

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	6FA	Standard for Fire Test of Valves	5	describes different plastics and valve types being made and installed with PTFE; in addition, it provides many examples of fluoroelastomers (FKM) valves that are used for API 6FA coverage	Annex A	Fluoropolymers and fluoroelastomers used in valves for their excellent sealing properties, resiliency, and thermal tolerance (often as a component in fire safety).	
Upstream	6J	Testing of Oilfield Elastomers	2	4.6 "conventional oilfield elastomers such as NBR are much more susceptible to storage degradation than chemically resistant materials such as fluoroelastomers"	4.6 storage conditions	While nitrile butadiene rubber (NBR) has some resistance, FKM and other fluoroelastomers have a much better and excellent resistance to chemicals, swelling, and deformation. In addition, FKM has a higher temperature range.	ISO 27914:2017 ISO 27916:2019

Segment	Designation	Name of Standard	Ed.	Content	Section(s)	Engineering Justification	ISO Reference
Upstream	15S	Spec for Spoolable Reinforced Plastic Line Pipe	3	4.2.1.1 "polymeric compounds shall be specified using the standard classification systems described in Table 1" 4.2.3 "polymer material used for cover layers manufactured by melt extrusion onto the pipe shall be specified using the standard classification systems described in Table 1" Table 1 requires PVDF cover layers to be specified by ASTM D5575 and ASTM D3222	4.2.3; 4.2.1.1; Table 1	PVDF used in piping for resiliency, chemical resistance, thermal tolerance, and flexibility. The PVDF covering material must comply with ASTM D5575 and D322 in these applications for reinforced plastic line piping.	

APPENDIX B

API SECOND SUBMISSION ON ECHA ANNEX XV RESTRICTION

September 11, 2023

European Chemicals Agency (ECHA)
Telakkakatu 6, 00150
Helsinki, Finland

RE: ECHA Annex XV Restriction Report: Per- and Polyfluoroalkyl substances (PFAS)

Dear Sir or Madam:

As a follow up to the July 31, 2023, submission of the American Petroleum Institute (API) to the European Chemicals Agency (ECHA) on its proposed restriction on per- and polyfluoroalkyl substances (PFAS), API respectfully offers a second submittal which provides exceptional analysis by Arcadis U.S. Inc (Arcadis). The attached Arcadis report further demonstrates the critical uses of certain PFAS, particularly fluoropolymers that researchers have shown meet the Organisation for Economic Co-operation and Development (OECD) criteria for “polymers of low concern,”¹ in the oil and natural gas industry.

API is the U.S. national trade association representing all facets of the oil and natural gas industry, which supports nearly 10 million U.S. jobs and 8% of the U.S. economy and provides critical energy to the European continent. While API represents North American-based companies, API membership includes multinational corporations with business in Europe and U.S. companies that trade with the European Union (EU), both of which would be significantly affected by the proposed PFAS restriction. API’s approximately 600 members include large integrated companies, as well as exploration and production, refining, marketing, pipeline, marine businesses, and service and supply firms.

Additionally, API is the global leader in convening subject matter experts across segments to develop, maintain, and distribute consensus standards and safety programs for the oil and natural gas industry. API’s goal is to enhance operational safety, environmental protection, and sustainability across the industry, especially through the global adoption of standards. API standards are developed under the American National Standards Institute (ANSI) accredited process, ensuring the standards are recognized not only for their technical rigor but also for their third-party accreditation. This accreditation facilitates the incorporation of API standards into regulations by state, federal, and international regulators. API’s July 31, 2023, submission to ECHA provided a thorough examination of API standards that specifically reference the direct use of PFAS in equipment and operations or require the use of PFAS-containing equipment to meet certain safety criteria – indicating their essential use in various equipment and materials to ensure operational safety and integrity across all segments of the industry.

In a separate undertaking, to better understand the extent of fluoropolymer use in the upstream (exploration and production), downstream (petroleum refining), and associated segments of the industry (e.g., transportation and storage), API contracted with Arcadis in early 2023 to evaluate the published literature and patents to identify the nature, volumes, and timing of PFAS use in these key segments. This search considered linings that might be present in piping, valves, flowmeters, and tanks; materials used in high-temperature and high-pressure applications such as gaskets, seals, rings, liners, and packer elements; cable and wiring insulation, including communication at the bottom of a well; and other applications necessary for safe operations. Additionally, attention was given to whether the fluoropolymers that are in use today can readily be replaced by alternative chemistries or techniques.

¹OECD “Data Analysis of The Identification Of Correlations Between Polymer Characteristics And Potential For Health Or Ecotoxicological Concern”; Joint Meeting Of The Chemicals Committee And The Working Party On Chemicals, Pesticides And Biotechnology. January 27, 2009: <https://www.oecd.org/env/ehs/risk-assessment/42081261.pdf>

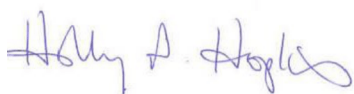
September 11, 2023

As the attached Arcadis summary report and accompanying detailed slide deck describe, Arcadis reviewed 18 fluoropolymers that researchers² determined fit the OECD criteria of “polymers of low concern” and identified solid fluoropolymer and equipment applications for 17 of the 18 fluoropolymers; no applications were identified for ionomer fluoropolymers. Of the 17 fluoropolymers with identified oil and natural gas applications, the upstream sector had more applications than the downstream sector, and PVDF (homopolymer) and FFKM exhibit the widest range of applications in the industry. A timeline tracking the introduction of these chemicals to the oil and natural gas industry was created based on patent data, stretching from 1997 to 2019. Benefits, patents, and applications of each fluoropolymer were researched and categorized as one of three fluoropolymer subtypes (fluoroplastics, fluoroelastomers, and specialty fluoropolymers). Specifically, within Appendix 1 of the Arcadis report, slide number 9 provides an extensive overview of uses in the oil and natural gas industry and slide number 13 illustrates that different polymers are suitable for various fluids and temperatures, emphasizing the benefits of fluoropolymer performance in extreme conditions. Under the section Research Findings, beginning on slide number 16, a review of each of the 17 fluoropolymers includes a description of its uses in the industry and the benefits provided. On slide number 48, limited alternatives for a few fluoropolymers were identified, including cautions on those applications.

The Arcadis review and findings further supports API’s previous recommendations to ECHA to reconsider components of the restriction, including the broad classification of all PFAS and applying the restriction to fluoropolymers, particularly those that meet the criteria for “polymers of low concern.” API additionally recommends inclusion of risk-based approaches. Finally, API urges ECHA to grant a permanent derogation for the essential uses of particular PFAS and fluoropolymers of low concern for all segments of the oil and natural gas industry, emphasizing that public exposure to these chemicals is minimal. PFAS-containing equipment and materials in the oil and natural gas industry do not have viable alternatives that effectively and consistently meet the unique, combined criteria of corrosion resistance, thermal tolerance, durability, excellent sealing properties, lubricity, dielectric strength, flexibility, and low flammability that are necessary to meet industry operational demands.

API appreciates the opportunity to provide additional supporting material for ECHA’s consideration as it reviews public input on the Annex XV Restriction Report: Per- and Polyfluoroalkyl substances (PFAS). Please feel free to contact us if you have questions or require additional information.

Sincerely,



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²Korzeniowski, S.H., Buck, R.C., Newkold, R.M., Kassmi, A.E., Laganis, E., Matsuoka, Y., Dinelli, B., Beauchet, S., Adamsky, F., Weilandt, K., Soni, V.K., Kapoor, D., Gunasekar, P., Malvasi, M., Brinati, G. and Musio, S. (2023), A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. *Integr Environ Assess Manag*, 19: 326-354. <https://doi.org/10.1002/ieam.4646>

Fluoropolymers in the Oil and Gas Industry

Literature Review

August 29, 2023

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Tables

Table 1 Fluoropolymers included in the literature review 1

Appendix

Appendix 1 Literature Search Slides

Executive Summary

Arcadis identified solid fluoropolymer applications for 17 of the 18 fluoropolymers of low concern; no applications were identified for ionomer fluoropolymers. Of the 17 fluoropolymers with identified oil and gas applications, the upstream sector had more applications than the downstream sector, and PVDF and FFKM exhibit the widest

range of applications. A timeline tracking the introduction of these chemicals to the oil and gas industry was created based on patent data, stretching from 1997 to 2019. Benefits, patents, and applications of each fluoropolymer were researched and presented as one of three fluoropolymer subtypes (fluoroplastics, fluoroelastomers, and specialty fluoropolymers). Alternatives to select fluoropolymers were identified.

1 Introduction

Arcadis U.S., Inc. (Arcadis) has prepared this report summarizing the methodology and findings of the literature review conducted on fluoropolymer use in the oil and gas industry for the American Petroleum Institute (API). Applications of solid fluoropolymers and equipment pre-coated with fluoropolymers (hereafter referred to as 'solid fluoropolymers') relevant to upstream and downstream oil and gas applications were the focus of this review. The list of fluoropolymers of interest in this review included four fluoropolymers identified in the peer-reviewed journal article by Henry et al. (2018) and 14 fluoropolymers identified in the peer-reviewed journal article by Korzeniowski et al. (2022). Collectively, the two articles identified the following 18 fluoropolymers as fluoropolymers of low concern, based on criteria established by the Organization for Economic Co-operation and Development (OECD).

Table 1 Fluoropolymers included in the literature review.

Fluoropolymer Abbreviation	Fluoropolymer Name
Amorphous	Amorphous fluoropolymers
CPT	Chlorotrifluoroethylene-tetrafluoroethylene
ECTFE copolymer	Ethylene-chlorotrifluoroethylene copolymer
ECTFE terpolymer	Ethylene-chlorotrifluoroethylene terpolymer
EFEP	Ethylene-tetrafluoroethylene-hexafluoropropylene
ETFE	Ethylene tetrafluoroethylene
FEP	Fluorinated ethylene propylene
FEPM	Trifluoroethylene-propylene copolymer
FEVE	Fluoroethylene-vinyl ether
FFKM	Tetrafluoroethylene-trifluoromethyl trifluorovinyl ether (TFE-PMVE) perfluoroelastomer
FKM	Hexafluoropropylene-vinylidene fluoride (HFP-VF2) polymer and hexafluoro-propylene-vinylidene fluoride-tetrafluoroethylene (HFP-VF2-TFE) polymers
Ionomer	Fluorinated ionomers
PCTFE	Polychlorotrifluoroethylene
PFA	Tetrafluoroethylene copolymers with perfluoroalkyl vinyl ethers (e.g., perfluoroalkoxy polymer, PFA)
PTFE	Polytetrafluoroethylene
PVDF copolymer	Polyvinylidene fluoride copolymer
PVDF homopolymer	Polyvinylidene fluoride homopolymer
THV	Tetrafluoroethylene-hexafluoropropylene-vinylidene fluoride (TFE-HFP-VF2) terpolymer

Detailed upstream and downstream applications for each of these solid fluoropolymers are presented in the accompanying slides (**Appendix 1**). An overview of the literature review methodology, findings, data gaps, and conclusions are presented in the text below.

2 Methodology

The literature search included journal articles, textbooks, databases, patents, and manufacturer/supplier websites. These sources were screened for relevance to research-specific keywords and search strings. In addition to the names and acronyms of the individual fluoropolymers identified for research in Table 1, the following list shows examples of keywords that were used in various combinations to search for known uses of fluoropolymers in the oil and gas industry:

- PFAS
- perfluoro
- fluoro
- fluoropolymers
- fluorinated polymers
- oil and gas
- petroleum
- perfluoroelastomer seals
- oil and gas wells
- oil production
- heat exchangers

Though many references were identified based on the searches performed, further screening to ensure that sources were relevant to the 18 fluoropolymers of focus and that they yielded a focused list of final references relevant to the literature review. Detailed citations are provided for each of the references in **Appendix 1**.

Findings for each of the 18 fluoropolymers were categorized by upstream and downstream use, fluoropolymer type, trade name(s), year of invention, years of active use, related patents, product types, and standards. Arcadis identified 26 ASTM International (ASTM) standards, 12 International Organization for Standardization (ISO) standards, and 22 API standards related to fluoropolymer use.

3 Key Findings

The 18 fluoropolymers of interest (Table 1) are high-performance polymers known for their thermal and chemical resistance, as well as their mechanical strength. These qualities make them well-suited for oil and gas applications, particularly in upstream applications, where durability, safety, and protection are crucial factors. Variations of these properties dictate which of the 18 fluoropolymers are used for specific oil and gas applications.

Arcadis identified solid fluoropolymer applications for 17 of the 18 fluoropolymers; no applications were identified for ionomer fluoropolymers. Four main uses for these 17 fluoropolymers were identified: cable insulations, pipe linings, sealing materials (such as in valves, pumps, and O-rings), and equipment coatings. The fluoropolymers

have more upstream applications than downstream applications. Furthermore, the literature suggests that PVDF and FFKM are used in the widest range of applications.

Arcadis constructed timelines to track the invention and usage of the 18 fluoropolymers within the oil and gas industry (**Appendix 1**). Specific dates of invention or market introduction were identified for 15 of the fluoropolymers. Only a general timeframe was determined for the remaining three: amorphous in the 1980s; ionomer in the mid-1960s; and FFKM in the mid-1970s. The timeline spans from 1937, when PCTFE was invented, to 2005, when the Neoflon CPT product line was launched.

Published patents were used to identify dates of invention specific to the oil and gas industry when possible. The following eight fluoropolymers were identified in such patents:

- FEP
- PFA
- PTFE/Expanded PTFE (ePTFE)
- ETFE
- CPT
- PVDF
- ECTFE
- Amorphous

The patent timeline starts in 1997 with the publication of Schlumberger's patent US 5,894,104 A, which patented a downhole cable insulated with fluoropolymer PFA. The timeline extends to 2019, when two patents were published: one for a multi-use oil and gas PVDF pipeline and another for a multi-layer tube/industrial pipe containing CPT, FEP, and PFA. Most patents identified were related to downhole cables or oil and gas pipelines. Further details are provided in **Appendix 1**.

Specific fluoropolymer benefits, patents, and applications for each of the 18 fluoropolymers are presented in **Appendix 1**, where they are organized by three fluoropolymer subtypes (fluoroplastics, fluoroelastomers, and specialty fluoropolymers) as categorized by Korzeniowski et al. (2022) and Henry et al. (2018). In addition to the 18 fluoropolymers, Xylan® is included. Xylan® is a brand-name fluoropolymer coating line composed of fluoropolymers such as PTFE, PFA, and FEP, combined with a reinforcing binder. Although not part of the original scope, Xylan® is included due to the presence of PTFE, PFA, and FEP in its composition and its widespread use in offshore drilling equipment.

4 Areas of Additional Study

Arcadis researched alternative materials for the above applications in a preliminary effort to understand how essential these 18 fluoropolymers are to the oil and gas industry. Alternatives for PTFE, PVDF, FKM and pre-coated equipment include well-known and frequently used materials, as well as new inventions. These alternatives are presented in **Appendix 1**. The performance of alternatives in comparison to the identified fluoropolymers is an area of active research and analysis.

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International Organization for Standardization. Available online at: <https://www.iso.org/standards.html>.

Korzeniowski S et al. 2022. A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management. 19 (2): 326-354.

Petroleum Abstracts. The University of Tulsa. TULSA® Database. Available online at <https://www.pa.utulsa.edu/products/tulsadatabase>.

The Society of Petroleum Engineers. OnePetro. Available online at <http://www.onepetro.org>.

URLs checked and confirmed on 29 August, 2023

Appendix 1

Literature Search Slides

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Fluoropolymers in the Oil and Gas Industry

A Literature Search for API

August 21, 2023

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Agenda

- 1 **Background**
- 2 **Research Findings: Overview of Uses**
- 3 **Research Findings: Specific Fluoropolymers**
- 4 **Research Findings: Standards that Identify Fluoropolymers**
- 5 **Final Notes**

Background

Fluoropolymers of Low Concern

Research focused on solid fluoropolymer applications and equipment pre-coated with aqueous fluoropolymers

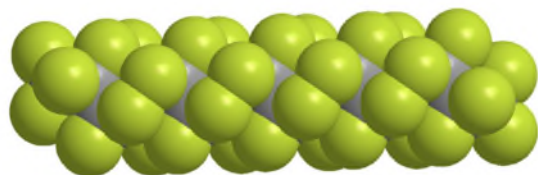


Figure 11.3 Three-dimensional representation of PTFE.

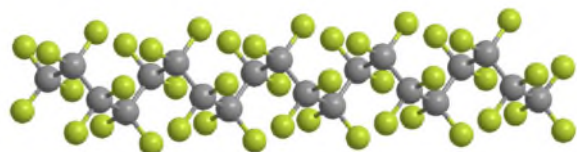


Figure 11.4 Ball and stick three-dimensional representation of PTFE.

(McKeen 2017)

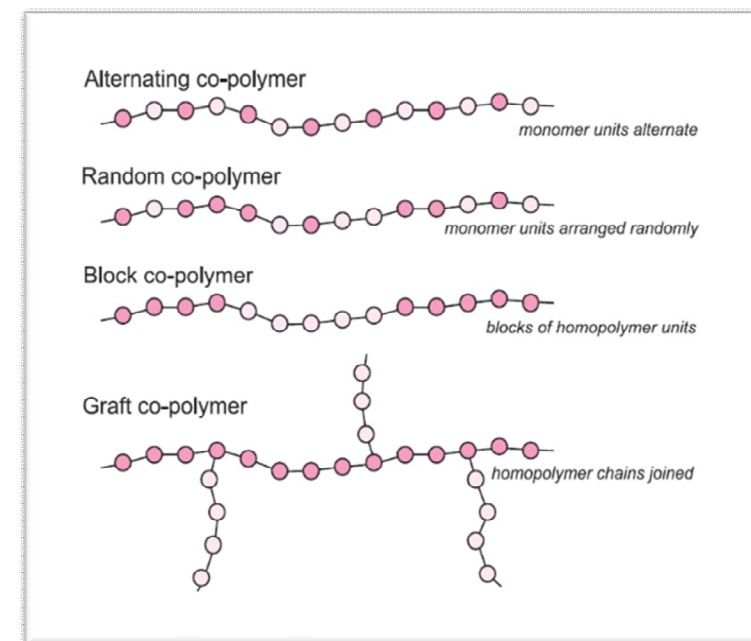
- Amorphous: Amorphous fluoropolymers
- CPT: Chlorotrifluoroethylene-tetrafluoroethylene
- ECTFE copolymer: Ethylene-chlorotrifluoroethylene copolymer
- ECTFE terpolymer: Ethylene-chlorotrifluoroethylene terpolymer
- EFEP: Ethylene-tetrafluoroethylene-hexafluoropropylene
- ETFE: Ethylene tetrafluoroethylene
- FEP: Fluorinated ethylene propylene
- FEPM: Trifluoroethylene-propylene copolymer
- FEVE: Fluoroethylene-vinyl ether
- FFKM: tetrafluoroethylene-trifluoromethyl trifluorovinyl ether (TFE-PMVE) perfluoroelastomer
- FKM: hexafluoropropylene-vinylidene fluoride (HFP-VF2) polymer and hexafluoropropylene-vinylidene fluoride-tetrafluoroethylene (HFP-VF2-TFE) polymers
- Ionomer: Fluorinated ionomers
- PCTFE: Polychlorotrifluoroethylene
- PFA: Tetrafluoroethylene copolymers with perfluoroalkyl vinyl ethers (e.g., perfluoroalkoxy polymer, PFA)
- PTFE: Polytetrafluoroethylene
- PVDF copolymer: Polyvinylidene fluoride copolymer
- PVDF homopolymer: Polyvinylidene fluoride homopolymer
- THV: tetrafluoroethylene-hexafluoropropylene-vinylidene fluoride (TFE-HFP-VF2) terpolymer

References:

McKeen M. 2017. Film Properties of Plastics and Elastomers. Fourth Edition. William Andrew.

Polymer Definitions Related to this Research

- **Polymer**: a large molecule composed of many smaller repeating units, known as monomers (Wade 1991)
 - **Homopolymer** – polymer composed of only one type of monomer (Thomas and Weimin 2009)
 - **Copolymer** – polymer composed of two or more types of monomers. Monomer units can have many arrangements (Thomas and Weimin 2009)
 - **Terpolymer** – polymer composed of three monomers (Gauthier 1995)
- **Elastomer**: polymer with elastic properties (Drobny 2009)



(University of York 2023)

References:

Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.
 Gauthier MM (ed.) 1995. Engineered Materials Handbook Desk Edition. ASTM International.
 Thomas S and Y Weimin (eds). 2009. Advances in Polymer Processing, From macro to nano scales. CRC Press. New York, NY.
 University of York, Department of Chemistry. Essential Chemistry Industry. <https://www.essentialchemicalindustry.org/polymers/polymers-an-overview.html>. Accessed online 5 June 2023.
 Wade, LG. 1991. Organic Chemistry. Prentice-Hall, Inc. Englewood Cliffs, NJ.

Literature Review Methodology

Relevant Sources Reviewed

- Over 20 journal articles
- Nine textbooks
- Over 10 patents
- Over 20 supplier websites
- OnePetro and TULSA databases
- ASTM and ISO databases
- Google Scholar



Research Findings:

Overview of Uses

Research Findings: Overview of Uses

Fluoropolymer Applications in the Oil and Gas Industry



- **Cable Insulations:**

- Fluoropolymers patented for cable insulations in deep drilling communications cables.
- Ensures reliable performance in challenging drilling environments.

- **Pipe Linings:**

- Fluoropolymer pipe linings used in oil pipelines, flexible tubing, and pipes.
- Enhances durability and resistance to corrosion.

- **Valves, Pumps, O-Rings, and Sealing Materials:**

- Fluoropolymers widely utilized in valves, pumps, o-rings, and sealing materials.
- Provides exceptional reliability and longevity in demanding oil and gas applications.

- **Coatings for Equipment:**

- Fluoropolymers employed in coatings for various equipment, including offshore marine uses.
- Offers increased performance and protection in harsh environments.

Overview of Uses – Upstream Applications

Fluoropolymer	Drilling Applications	Oil/ Gas Production	Formation Evaluation	Offshore Exploration	General Upstream Use Applicable to Multiple Categories
Fluoroplastics					
CPT					✓
ECTFE ¹	✓	✓			
EFEP		✓			
ETFE	✓				
FEP	✓			✓	✓
FEVE				✓	
PFA	✓				✓
PTFE	✓				✓
PVDF ²	✓	✓		✓	✓
THV	✓	✓			✓
PCTFE	No upstream uses identified.				
Fluoroelastomers					
FEPM		✓			
FFKM	✓	✓	✓		✓
FKM	✓	✓			✓
Specialty					
Amorphous	No upstream uses identified.				
Ionomer	No upstream uses identified.				

Footnotes:

1. Includes both the co- and terpolymer of ECTFE.
2. Includes both the homo- and copolymer of PVDF.

Overview of Uses – Downstream Applications

Fluoropolymer	Hydrocarbon Processing	Natural Gas/Oil Delivery	General Downstream Use Applicable to Multiple Categories
Fluoroplastics			
CPT			✓
ECTFE ¹	No downstream uses identified		
EFEP		✓	
ETFE	No downstream uses identified		
FEP			
FEVE			
PFA		✓	
PTFE		✓	✓
PVDF ²		✓	✓
THV			✓
PCTFE	✓		
Fluoroelastomers			
FEPM			
FFKM	✓	✓	✓
FKM	✓		
Specialty			
Amorphous	✓		
Ionomer	No downstream uses identified		

Footnotes:

1. Includes both the co- and terpolymer of ECTFE.
2. Includes both the homo- and copolymer of PVDF.

Overall Use Takeaways



More identified applications in the upstream sector compared to downstream



Our research identified polyvinylidene fluoride (PVDF) and Kalrez (FFKM) as the fluoropolymers with the widest variety of O&G applications

Fluoropolymers: Optimal Performance in Extreme Conditions

- Different polymers are suitable for various fluids and temperatures.
- Upstream applications (e.g., offshore and deep drilling) require higher temperature, pressure, and corrosion resistance.

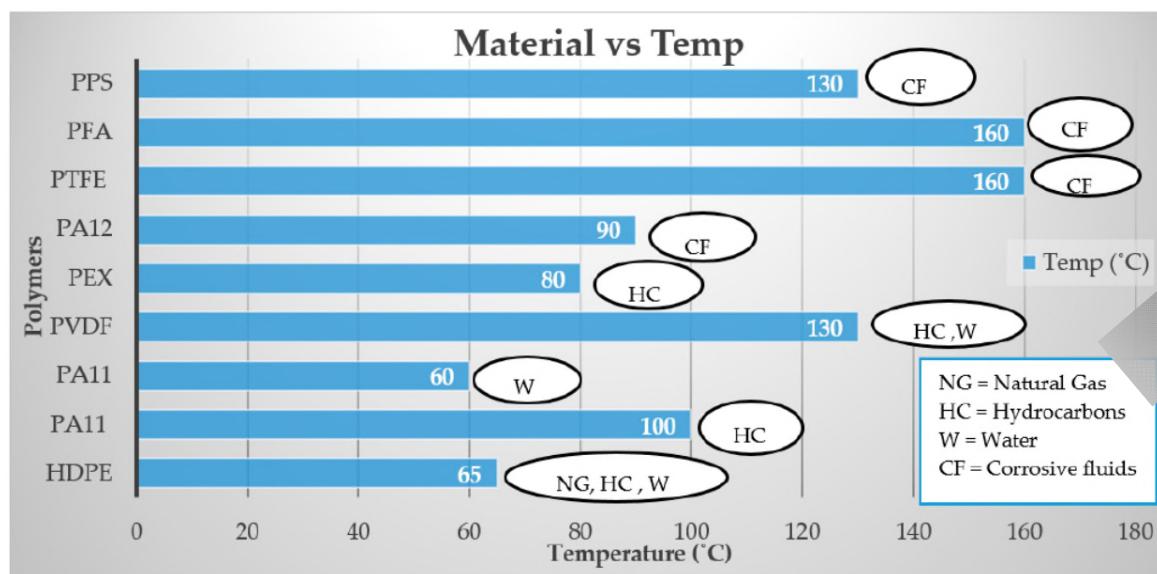
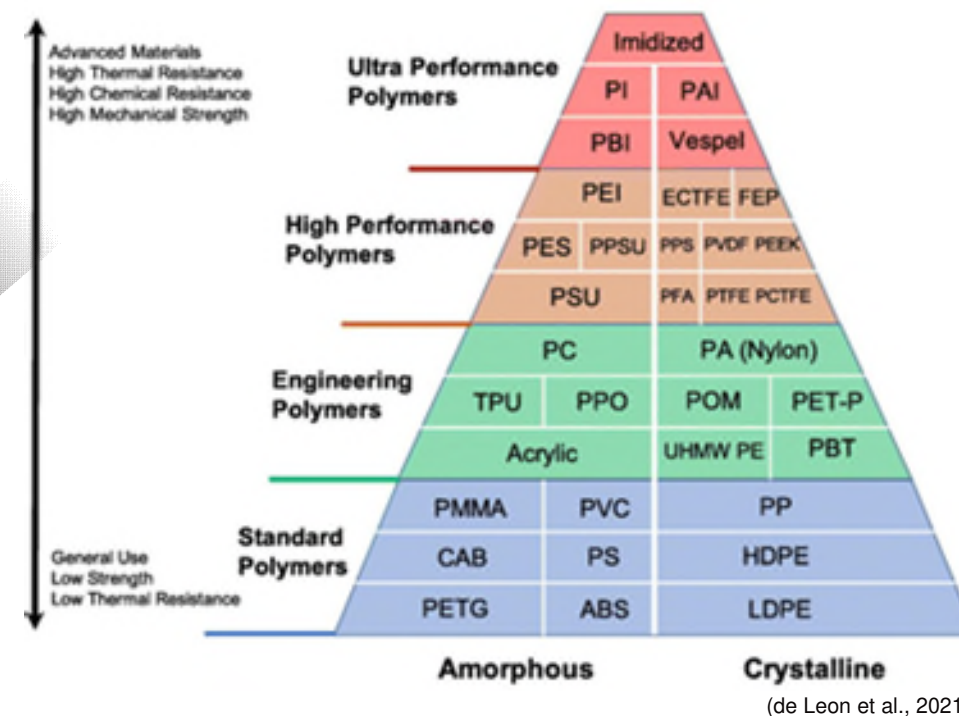


Figure 8. Temperature limits for Polymers.

(Khalid et al., 2020)

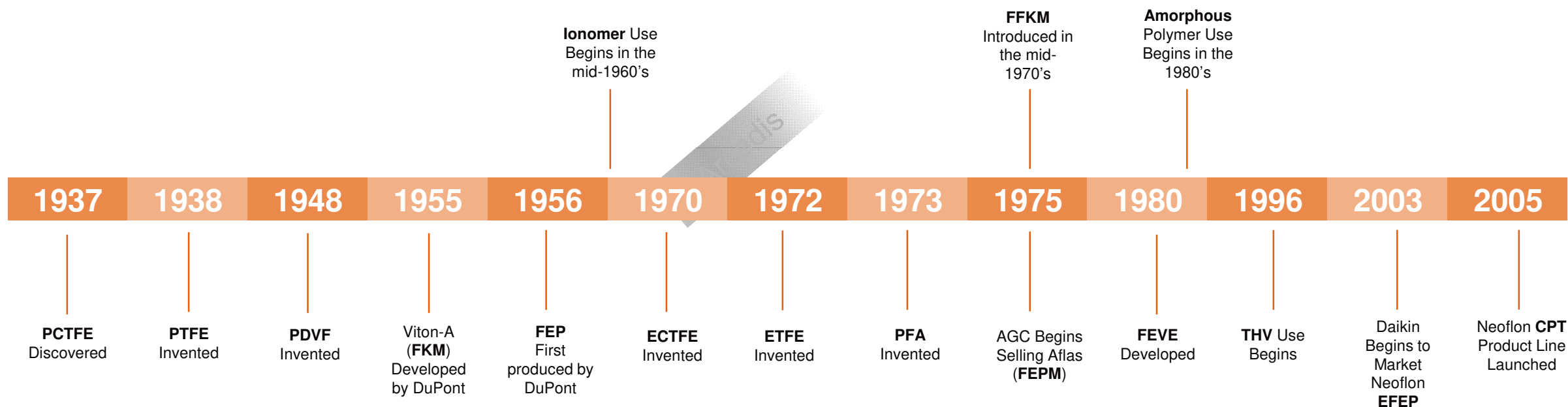


References:

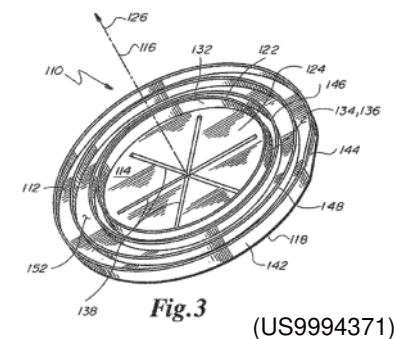
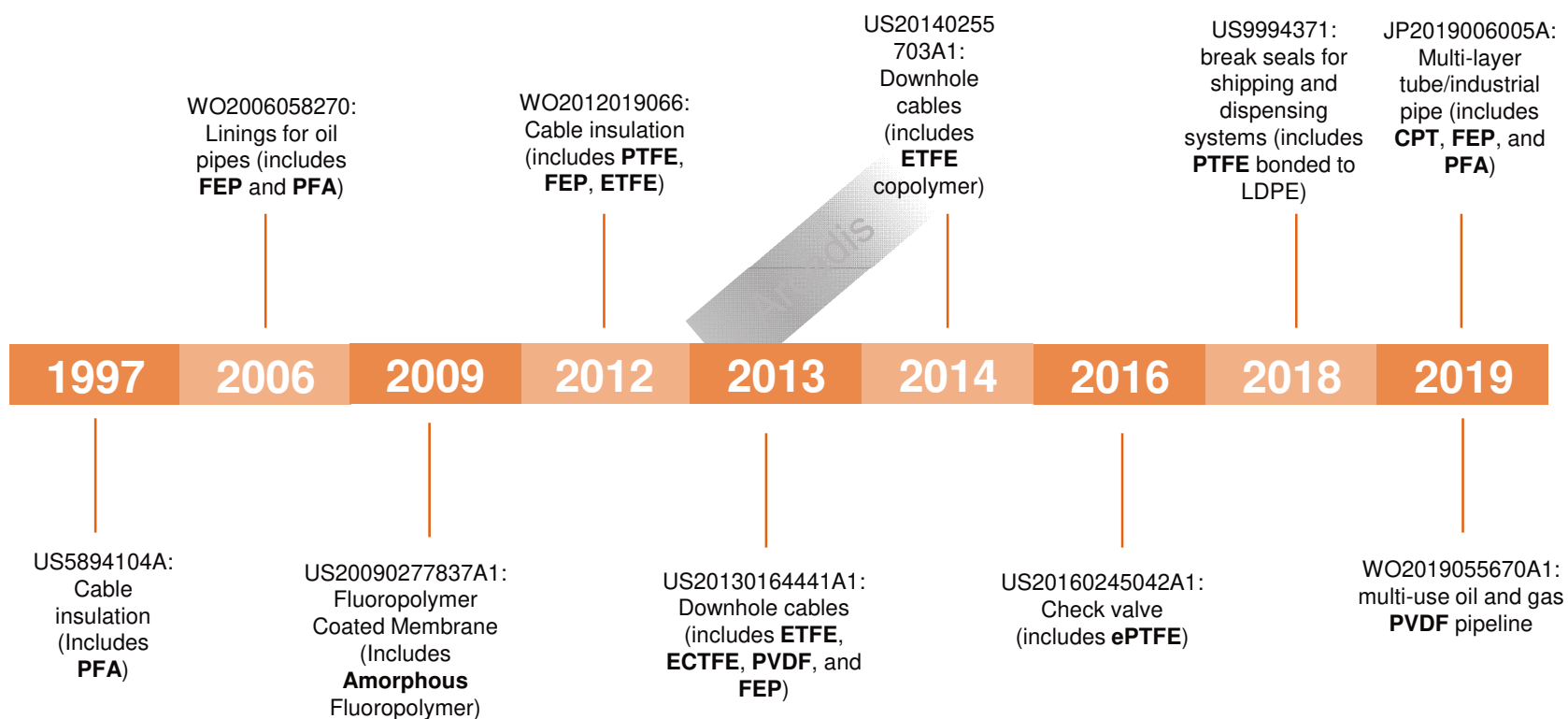
de Leon et al. 2021. High performance polymers for oil and gas applications. <https://www.sciencedirect.com/science/article/pii/S1381514821000705>

Khalid, H. U., M. C. Ismail, and N. Nosbi. 2020. Permeation Damage of Polymer Liner in Oil and Gas Pipelines: A Review. *Polymers*. 12, 2307.

Chronology of Fluoropolymer Invention and Manufacturing



Chronology of Fluoropolymers O&G Related Patents



- Earliest patent use identified in 1997
- Fluoropolymers patented for O&G:
 - FEP
 - PFA
 - PTFE/ePTFE
 - ETFE
 - CPT
 - PVDF
 - ECTFE
 - Amorphous

Research Findings:

Specific Fluoropolymers

Fluoroplastics

Fluoroelastomers

Specialty

Arcadis

Fluoroplastics

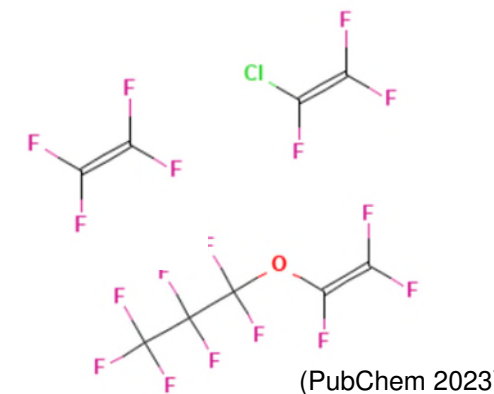
Arcadis

CPT (chlorotrifluoroethylene-tetrafluoroethylene)

Trade names include: Neoflon CPT, Neofron CPT

- **Uses in the O&G industry:**
 - *Patented Use (Japan):* Multilayer industrial tube with an inner layer and an outer layer are constituted by a fluorine resin (Onoda et al. 2017)
- **Benefits of this fluoropolymer:**
- Good flexibility and excellent permeation resistance to organic solvents, water, vapor and gasoline
 - Hot melt adhesion to the other plastics such as polyamide with its reactive group
 - (Daikin 2018)
- **Development:**
 - Developed specifically by Daikin (NEOFLON product launched in 2005)

Terpolymer of chlorotrifluoroethylene, tetrafluoroethylene, and perfluoroalkyl-vinyl-ether. (Korzeniowski et al. 2022)



References:

Daikin. 2012. Business Overview Daikin Fluorochemical Products. January.

Daikin, "Neoflon CPT LP-1000," tds-lp-1000-E_ver01, March 2018.

Korzeniowski S et al. 2022. A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management. 19 (2): 326-354.

Onoda, K., Okoda, T., and Hosoya, A., inventors; AOI Co Ltd, assignee. Glide flex tube. Japanese Patent JP 2019-006005 A. 17 Jan 2019.

PubChem. National Institutes of Health. <https://pubchem.ncbi.nlm.nih.gov/>. Accessed online 5 June 2023.

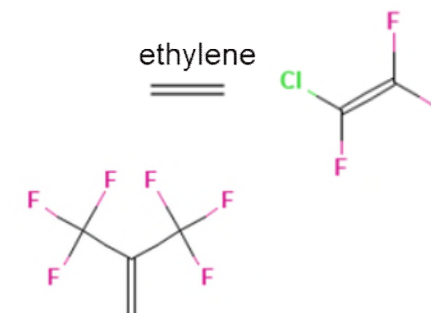
ECTFE terpolymer (ethylene-chlorotrifluoroethylene terpolymer)

Trade names include: No names specific to the terpolymer identified

- **Uses in the O&G industry:**
 - No uses specific to the terpolymer identified
- **Benefits of this fluoropolymer:**
- Semicrystalline and fully-fluorinated melt processable fluoropolymer
- Better mechanical, abrasion, and radiation resistance compared to PTFE and other perfluoropolymers (Ebnesajjad 2013)
- **Development:**
 - No development information specific to the terpolymer identified

Terpolymer of ethylene, chlorotrifluoroethylene, and hexafluoroisobutylene

(Korzeniowski et al. 2022)



(PubChem 2023)

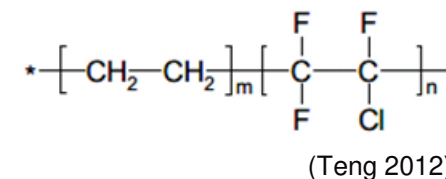
References:

DeLeon et al. 2021. High performance polymers for oil and gas applications. <https://www.sciencedirect.com/science/article/pii/S1381514821000705>
 Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew
 Korzeniowski S et al. 2022. A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management. 19 (2): 326-354.
 PubChem. National Institutes of Health. <https://pubchem.ncbi.nlm.nih.gov/>. Accessed online 5 June 2023.

ECTFE copolymer (ethylene-chlorotrifluoroethylene copolymer)

Trade names include: Halar

- **Uses in the O&G industry:**
 - Halar ECTFE is used for cable jacketing and insulation in downhole cables (Solvay 2017)
 - Powder-coated tanks and ducts (Drobny 2009; Solvay 2017)
- **Benefits of this fluoropolymer:**
 - Hardness/toughness
 - **Transparent**
 - Resistant to most chemicals except hot polar and chlorinated solvents
 - It does not stress, crack or dissolve in any solvents
 - Better barrier to SO₂, Cl₂, HCl, and water than FEP and PVDF.
- **Development:**
 - Partially fluorinated polymer developed by Solvay in 1970
 - (Ebnesajjad 2013)



Example of Halar ECTFE used for cable jacketing (Solvay 2017)

References:

DeLeon et al. 2021. High performance polymers for oil and gas applications. <https://www.sciencedirect.com/science/article/pii/S1381514821000705>
Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.
Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew
Solvay Specialty Polymers. 2017. High Performance Polymers for Oil & Gas. R05/2017/Version 2.5.
Teng, H. 2012. Overview of the Development of the Fluoropolymer Industry. Applied Sciences. 2, 496-512.

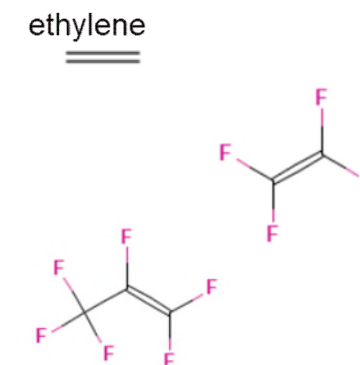
EFEP (ethylene-tetrafluoroethylene-hexafluoropropylene)

Trade names include: Neoflon EFEP

- **Uses in the O&G industry:**
 - Used in thermoplastic umbilicals, tubing extrusion and injection molding, extrusion of thin-walled tubing
 - (Berger et al. 2014)
- **Benefits of this fluoropolymer:**
- Can be coextruded with other resins such as polyamides and can form strong bonds between the layers
 - Can bond to non-fluoropolymers
 - (Daikin 2022)
- **Development:**
 - Developed by Daikin, and first marketed in 2003
 - (History of Daikin Innovation 2023)

Terpolymer of ethylene, tetrafluoroethylene, and hexafluoropropylene

(Korzeniowski et al. 2022)



(PubChem 2023)

References:

Berger, J., Franosch, J., and Dowe, A. 2014. Direct bonding, adhesive-free Multilayer Thermoplastic Systems for Oil & Gas Pipelines, Risers and Umbilicals. In Proceedings of the Offshore Technology Conference, Houston, Texas.

Daikin, "Neoflon® EFEP RP-5101," TDS-EFEP-RP-004 REV 0, November 2022.

History of Daikin Innovation. 2023. Available online at: https://www.daikin.com/air/daikin_achievements/innovation. Retrieved June 7, 2023.

Korzeniowski S et al. 2022. A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management. 19 (2): 326-354.

PubChem: National Institutes of Health. <https://pubchem.ncbi.nlm.nih.gov/>. Accessed online 5 June 2023.

ETFE (ethylene tetrafluoroethylene)

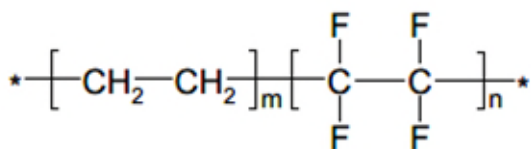
Trade names include: Chemours Tefzel, Asahi Glass Fluon, 3M Dyneon

- **Uses in the O&G industry:**

- *Patented Use:* Downhole cables for deep drilling (especially in colder climates) (Lahijani 2012)

- **Development:**

- Invented in 1972 (Ebnesajjad 2013)



(Teng 2012)

- **Benefits of this fluoropolymer:**

- Can withstand extreme temperatures, ranging from -200 to 150°C
- Good for low temperature storage
- Exhibits excellent resistance to various chemicals
- Demonstrates strong mechanical properties, including high tensile strength and elongation, surpassing many other fluoropolymers
- Highly resistant to weathering and aging processes
- Excellent dielectric properties, making it suitable for electrical applications
- Possesses nonstick characteristics, making it resistant to sticking and adhesion
- Higher tensile strength than PTFE, FEP, and PFA because its molecular chains adopt a planar zigzag configuration
- (Drobny 2009)

References:

Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.
 Ebnesajjad, S. (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew.
 Lahijani, J., inventor; E. I. Du Pont De Nemours And Company, assignee. Downhole well communications cable. International Patent WO 2012/019066 A1. 9 Feb 2012.
 Teng, H. 2012. Overview of the Development of the Fluoropolymer Industry. Applied Sciences. 2, 496-512.

FEP (fluorinated ethylene propylene)

Trade names include: Dyneon FEP, F46, Fluororesin-46, Neoflon FEP, Niflon FEP, Teflon FEP

• **Uses in the O&G industry:**

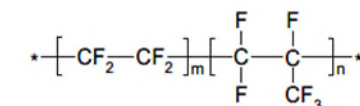
- Lined tanks
- Lined pipes and fittings
 - Oil pipe lining (*patented use*)
- Down-hole cables (*patented uses*)
 - Cable insulation (*patented use*)
- Over braided hose
- Component parts of valves
- Gaskets
- Heat exchangers
- (Drobny 2009; Aten et al. 2014; Lahijani 2009; Magner et al. 2013; McKeen et al. 2006; Onodora et al. 2019)

• **Benefits of this fluoropolymer:**

- Retains most of the favorable properties of PTFE, but its melt viscosity is low enough for conventional melt processing
- Resists most chemicals and solvents, even at elevated temperatures and pressures
- Gases and vapors permeate at a rate that is lower than for most plastics
- Resists the effects of weather, extreme heat, and UV radiation (Drobny 2009)

• **Development:**

- First produced by DuPont in 1956 (Teflon™ FEP) to reduce PTFE's high crystallinity and melt viscosity (Ebnesajjad 2013)



(Teng 2012)

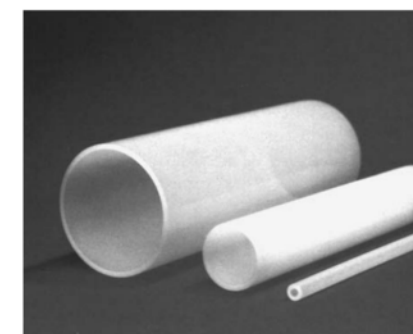


FIGURE 4.16 Extruded pipes from FEP. (Courtesy of DuPont.)

(Drobny 2009)

References:

- Aten, R.M., Burch, H.E., Turner, J.F., Young, R.T., Campbell, K.L., inventors; Chemours Co FC LLC, assignee. Adhesion of Fluoropolymer to Metal. United States Patent US 2014/0255703 A1. 11 Sep 2014.
- Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.
- Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew
- Lahijani, J., inventor; E. I. Du Pont De Nemours And Company, assignee. Downhole well communications cable. International Patent WO 2012/019066 A1. 9 Feb 2012.
- Magner, S., inventor; RSCC Wire and Cable LLC, assignee. Down-Hole Cable Having a Fluoropolymer Filler Layer. United States Patent US 2013/0164441 A1. 27 Jun 2013.
- McKeen, L.W., Mohan, P.K., Mestemacher, S.A., Farnsworth, K.D., and Obal, W.D., inventors; E.I. DuPont De Nemours And Company, assignee. Coated pipes for harsh environments. International Patent WO 2006/058270 A1. 6 Jan 2006.
- Onoda, K., Okada, T., and Hosoya, A., inventors; AOI Co Ltd, assignee. Glide flex tube. Japanese Patent JP 2019-006005 A. 17 Jan 2019.
- Teng, H. 2012. Overview of the Development of the Fluoropolymer Industry. Applied Sciences. 2, 496-512.

FEVE (fluoroethylene-vinyl ether)

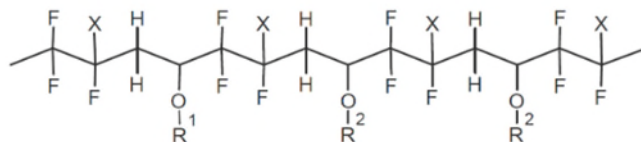
Trade names include: Lumiflon (PFEVE)

- **Uses in the O&G industry:**

- Coatings for offshore and marine structures like oil rigs, tanks, and vessels
- (Darden et al. 2007; AGC 2018)

- **Development:**

- Developed in the early 1980's, primarily used in architectural markets because of FEVE's gloss and color retention properties
- (Ebnesajjad 2013)



(Chemical Retrieval on the Web 2023)

- **Benefits of this fluoropolymer:**

- Curable at ambient temperatures
- Low permeability to oxygen, water and chloride, which offers high degradation resistance when exposed to airborne pollutants and other environmental conditions
- Easily repairable and often used as a restorative product to repair previously degraded PVDF applications.
- Can last for up to 30 to 60 years
- (FEVE vs. PVDF 2021; Drobny 2009)

References:

AGC: FEVE-Based Coatings Protect Offshore, Marine Structures. 2018. Available online at: https://www.coatingsworld.com/contents/view_breaking-news/2018-05-29/agc-feve-based-coatings-protect-offshore-marine-structures/. Retrieved June 7, 2023.

Chemical Retrieval on the Web. 2023. "FLUOROETHYLENE VINYL ETHER (FEVE)". <https://polymerdatabase.com/Polymer%20Brands/FEVE.html>. Accessed 1 June 2023.

Darden, W., Takayanagi, T., Masuda, S., and Kimura, I. 2007. Fluoroethylene Vinyl Ether Resins for Applications in Marine Environments. In Proceedings of the NACE International Corrosion Conference and Expo, Nashville, Tennessee.

Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.

Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew

Fluoroethylene Vinyl Ether (FEVE) Versus Polyvinylidene Fluoride (PVDF): A Exploration Of The Benefits Of FEVE Resin Technology. 2021. Available online at: <https://lumiflonusa.com/technical/fluoroethylene-vinyl-ether-feve-versus-polyvinylidene-fluoride-pvdf-a-exploration-of-the-benefits-of-feve-resin-technology/>. Retrieved June 7, 2023.

PFA (tetrafluoroethylene copolymers with perfluoroalkyl vinyl ethers)

Trade names include: Hyflon PFA (Solvay Solexis)

• **Uses in the O&G industry:**

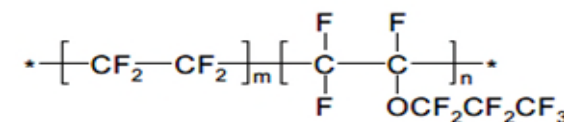
- Cable insulation (*patented use; US5894104A*)
- Linings for oil pipes (*patented use; WO2006058270*)
- Downhole cables (*patented use; US20140255703A1*)
- Downhole cables and control lines
- Multi-layer tubes (*patented use; JP2019006005A*)
- Corrosion protection on steel pipes
- (Hedberg 1999; McKeen et al. 2006; Aten et al. 2014)
- (Onoda et al. 2019; Solvay 2017)

• **Benefits of this fluoropolymer:**

- Melt processible
- Continuous use temperature of 260 °C
- (Drobny 2009; Ebnesajjad 2013)

• **Development:**

- Introduced in 1973
- (Ebnesajjad 2013)



(Teng 2012)

References:

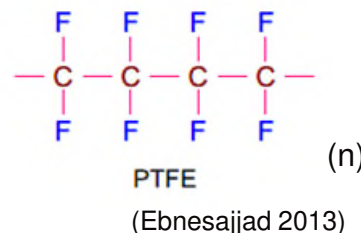
- Aten, R.M., Burch, H.E., Turner, J.F., Young, R.T., Campbell, K.L., inventors; Chemours Co FC LLC, assignee. Adhesion of Fluoropolymer to Metal. United States Patent US 2014/0255703 A1. 11 Sep 2014.
- Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.
- Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew.
- Hedberg, H., inventor; Schlumberger Technology Corporation (Schlumberger NV), assignee. Coax-slickline cable for use in well logging. United States Patent US 5,894,104 A. 13 Apr 1999.
- McKeen, L.W., Mohan, P.K., Mestemacher, S.A., Farnsworth, K.D., and Obal, W.D., inventors; E.I. DuPont De Nemours And Company, assignee. Coated pipes for harsh environments. International Patent WO 2006/058270 A1. 6 Jan 2006.
- Onoda, K., Okoda, T., and Hosoya, A., inventors; AOI Co Ltd, assignee. Glide flex tube. Japanese Patent JP 2019-006005 A. 17 Jan 2019.
- Solvay Specialty Polymers. 2017. High Performance Polymers for Oil & Gas. R05/2017/Version 2.5.
- Teng, H. 2012. Overview of the Development of the Fluoropolymer Industry. Applied Sciences. 2, 496-512.

PTFE (polytetrafluoroethylene)

Trade names include: Teflon (DuPont/Chemours), Dyneon PTFE, Daikin Polyflon

- **Uses in the O&G industry:**

- O-rings and sealants
 - Ex: Teflon Lip Seal in Centrifugal Pump
- Coatings on stud bolts and threaded fasteners
- Coatings for oil and gas well tubulars
- ePTFE check valve (*patented use; US20160245042A1*)
- Cable insulation (*patented use; WO2012019066*)
- Linings for oil pipes
- Tank linings
- Shoe for oil pipeline
- (Dhami 2018; Gluge et al. 2020; Lahijani et al. 2012; Napier et al. 2016)
- (Products: Fluoropolymer Tank Lining 2023; Habonium 2018; Centrifugal Pump 350.205-11.25)
- (StreaMax Coating Systems 2023; Trans-Alaska Pipeline 2019)



- **Benefits of this fluoropolymer:**

- One of the lowest surface energies among the organic polymers
- Most chemically resistant organic polymer
- One of the most thermally stable among the organic polymers
- Melting point and specific gravity are more than double those of PE
- Insoluble in common solvents
- (Ebnesajjad 2013; 2017)

- **Development:**

- PTFE was discovered in 1938 by Roy Plunkett of DuPont
- Patent issued to DuPont in 1941 to recognize its rights to the invention
- In 1950, DuPont scaled up the commercial production of Teflon®
- (Ebnesajjad 2013; 2017)

References: Available on next slide.

PTFE (polytetrafluoroethylene)

Trade names include: Teflon (DuPont/Chemours), Dyneon PTFE, Daikin Polyflon

References:

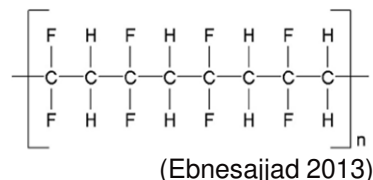
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- Napier, W.J., Harp, G.P., inventors; L Gore and Associates Inc, assignee. Fluoropolymer article for downhole applications. United States Patent US 2016/0245042 A1. 25 Aug 2016.
- Products: Fluoropolymer tank lining. 2023. Available online at: <https://www.nichias.co.jp/en/products/detail/167>. Retrieved June 7, 2023.
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- Centrifugal Pump 350.205-11.25*. 2022. Available online at: <http://www.drillingsolutionsltd.com/halliburton-centrifugal-pump-parts-list.html>. Retrieved June 7, 2023.
- StreaMax™ Coating Systems. 2023. Available online at: <https://www.teflon.com/en/industries-and-solutions/solutions/productivity-efficiency-flow/streamax-coatings>. Retrieved June 7, 2023.
- Trans-Alaska Pipeline. 2019. Available online at: <https://www.underwater.org/mermaid/passage/pipeline/index.html>. Retrieved June 7, 2023.

PVDF homopolymer (polyvinylidene fluoride homopolymer)

Trade names include: KF, Hylar, Kynar, Solef

- **Uses in the O&G industry:**

- Flexible risers and flowlines
- Pipes:
 - Pipe liners
 - Flexible pipe
 - Multi-layer coated flexible pipeline (*use starting in 1970s*)
- Umbilicals
- Liners in choke and kill lines
- Downhole wire & cables
 - Downhole cable (*patented use; US20130164441A1*)
- (Berger et al 2014; Magner 2013)
- (Solvay 2017; Extreme materials 2023)



- **Benefits of this fluoropolymer:**

- Highest flexural modulus among the known commercial fluoropolymers
- Mechanically stronger than perfluorinated polymers like PTFE
- Resistance to abrasion
- Resists both creep under long-term stress and fatigue during cyclic loading
- Good thermal stability, making it suitable for high-temperature applications
- Resistant to ultraviolet (UV) and higher energy radiation
- Excellent resistance to most chemicals and solvents
- Not hygroscopic, meaning it does not absorb significant amounts of water
- Adsorbs less than 0.05% of water at room temperature
- (Ebnesajjad 2013; Drobny 2009)

- **Development:**

- The first successful aqueous polymerization of vinylidene fluoride was reported in 1948. In 1960, a manufacturing process was developed, and PVDF was first introduced to the market (Ebnesajjad 2013; Drobny 2009).

References:

Berger, J., Franosch, J., and Dowe, A. 2014. Direct bonding, adhesive-free Multilayer Thermoplastic Systems for Oil & Gas Pipelines, Risers and Umbilicals. In Proceedings of the Offshore Technology Conference, Houston, Texas.

Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.

Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew.

Extreme materials for extreme environments Offshore. 2023. Available online at: <https://hpp.arkema.com/en/markets-and-applications/oil-and-gas/offshore/>. Retrieved June 7, 2023.

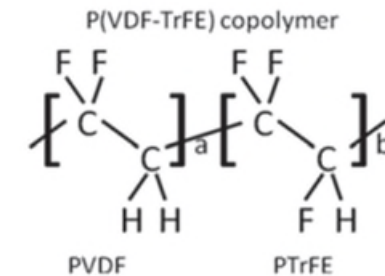
Magner, S. inventor; RSCC Wire and Cable LLC, assignee. Down-Hole Cable Having a Fluoropolymer Filler Layer. United States Patent US 2013/0164441 A1. 27 Jun 2013.

Solvay Specialty Polymers. 2017. High Performance Polymers for Oil & Gas. R05/2017/Version 2.5.

PVDF copolymer (polyvinylidene fluoride copolymer)

Trade names include: KYNAR

- **Uses in the O&G industry:**
 - No uses of the copolymer specifically identified
- **Benefits of this fluoropolymer:**
 - Higher flexibility, chemical resistance, elongation, solubility, impact resistance, optical clarity, and thermal stability during processing than PVDF homopolymer (Ebnesajjad 2013; Drobny 2009)
 - Resists creep (deformation of the product)
 - Can be irradiated (used in biopharma industry)
- **Development:**
 - The first successful aqueous polymerization of vinylidene fluoride was reported in 1948
 - In 1960, a manufacturing process was developed, and PVDF was first introduced to the market (Ebnesajjad 2013; Drobny 2009)



(Example from Mao et al. 2011)

References:

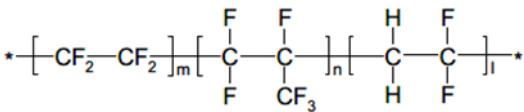
Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.
Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew.
Mao, D. & Gnade, Bruce & Quevedo-Lopez, Ma. (2011). Ferroelectric Properties and Polarization Switching Kinetic of Poly (Vinylidene Fluoride-Trifluoroethylene) Copolymer. 10.5772/17147.

THV (THV-HFP-VF2)

tetrafluoroethylene-hexafluoropropylene-vinylidene fluoride terpolymer

Trade names include: Dyneon THV, Nowoflon THV, Altafluor 350 (THV FLEX)

- **Uses in the O&G industry:**
 - Downhole cables (*patented use; US20140255703A1*)
 - Flexible tubing
 - Tank lining
 - (Altafluor 2023; Aten et al 2014; Dyneon 2000)
- **Benefits of this fluoropolymer:**
 - Low processing temperature
 - Ability to bond to elastomers and hydrocarbon-based plastics
 - Flexibility
 - Optical clarity
 - (Ebnesajjad 2013; Drobny 2009; Dyneon 2000)
- **Development:**
 - Use begins in 1996 - predominantly used for thin film technology (Teng 2012)



(Teng 2012)

Applications	Wire/Cable & Heat Shrink Tubing	Tank & Pipe Liners
Low Temp. Processing	✓	✓
Chemical & Permeation Resistance	✓	✓
Flexibility	✓	✓
Optical Clarity	✓	
Bondability & Weldability	✓	✓
E-beam Curable	✓	
Weatherability	✓	✓
Self-Extinguishing	✓	✓

References:
Altafluor 350 THV Flex Tubing. 2023. Available online at: <https://www.altaflo.com/products/thv-flex-altafluor-350/>. Retrieved June 7, 2023.
Aten, R.M., Burch, H.E., Turner, J.F., Young, R.T., Campbell, K.L., inventors; Chemours Co FC LLC, assignee. Adhesion of Fluoropolymer to Metal. United States Patent US 2014/0255703 A1. 11 Sep 2014.
Drobny, J.G. 2009. Technology of Fluoropolymers. 2nd Edition, CRC Press, Boca Raton, FL.
Dyneon. 2000. Dyneon Fluorothermoplastics Product Information. Issued 12/00.
Ebnesajjad S (editor). 2013. Introduction to Fluoropolymers: Materials, Technology, and Applications. William Andrew.
Teng, H. 2012. Overview of the Development of the Fluoropolymer Industry. Applied Sciences. 2, 496-512.

PCTFE (polychlorotrifluoroethylene)

Trade names include: Kel-F 81, Kel-F 300, Hostaflon C2, Fluon, Halon, Aclar, Neoflon-PCTFE, Voltalef

- **Uses in the O&G industry:**

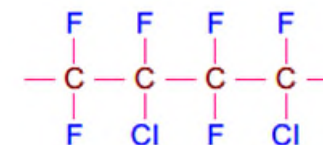
- Seals
- Gaskets (especially for liquefied natural gas applications)
- Seat, anti-abrasion rings in three-piece ball valves
- (Habonium 2018)

- **Benefits of this fluoropolymer:**

- Exceptional barrier properties and chemical resistance
- Sensitive to organic solvents
- Low thermal stability, requires careful processing (Ebnesajjad 2013; Drobny 2009)
- Can be made into transparent sheets
- Good in cryogenic environments

- **Development:**

- Developed in 1937, one year before PTFE (Ebnesajjad 2013)



(Ebnesajjad 2013)

Fluoroelastomers

Arcadis

FEPM (trifluoroethylene-propylene copolymer)

Trade names include: AFLAS FEPM, Viton Extreme

- **Uses in the O&G industry:**

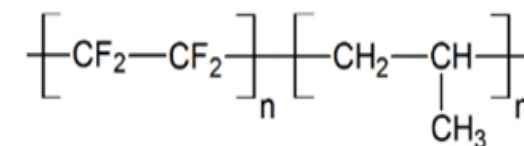
- O-rings, seals, gaskets, wire and cable coating (AGC 2018)

- **Benefits of this fluoropolymer:**

- Resistant to acids and bases, low dielectric constant (AGC 2018; McKeen 2017)

- **Development:**

- Manufactured in Japan, marketed in US, differs from Viton and Fluorel by adding polypropylene to the fluorine monomer (tetrafluoroethylene)
- AGC begins to market AFLAS FEPM in 1975 (AGC 2018)



(Chemical Retrieval on the Web 2023)

References:

AGC Chemicals Inc. 2018. Aflas Fluoroelastomers. CA011E.

Chemical Retrieval on the Web. 2023. "FEPM – TETRAFLUOROETHYLENE PROPYLENE". <https://polymerdatabase.com/Elastomers/FEPM.html>. Accessed 1 June 2023.

McKeen M. 2017. Film Properties of Plastics and Elastomers. Fourth Edition. William Andrew.

FKM

(Fluorine Kautschuk Material; HFP-VF2 polymer and HFP-VF2-TFE polymers)

Trade names include: Viton, Viton-A, Viton-B, “fluoro-rubber”

• **Uses in the O&G industry:**

- O-rings
- Expansion joints
- Diaphragms
- Blow-out preventers
- Valve seats
- Gaskets
- Hose
- Safety clothing and gloves
- Stack and duct coatings
- Tank linings
- Drill bit seals
- V-ring packers
- (DuPont 2023; 2021; Fluorocarbon O-Ring 2023; Habonium 2018; Kalrez Parts 2023)
- (Viton™ Fluoroelastomers for Oil and Gas Exploration and Production 2023)

• **Benefits of this fluoropolymer:**

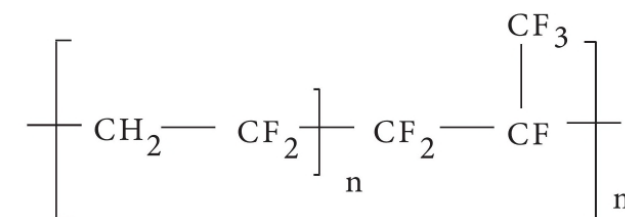
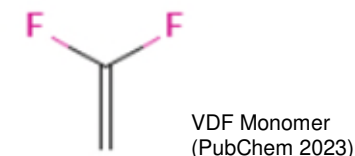
- Temperature and fuel resistant
- (McKeen 2017; DuPont 2023)

• **Development:**

- Viton-A (FKM) developed by DuPont in 1955
- (Uschold 1985; Byrdson 1994)

FKM fluoroelastomers contain vinylidene fluoride (VDF) as a monomer combined with a variety of other fluoromonomers

(Korzeniowski et al. 2022)



Viton (Departamento de Ciência e Tecnologia Aeroespacial, Brazil)

FKM

(Fluorine Kautschuk Material; HFP-VF2 polymer and HFP-VF2-TFE polymers)

Trade names include: Viton, Viton-A, Viton-B, “fluoro-rubber”

References:

Brydson J. A. 1994. Specialty Rubbers. Smithers Rapra.

DuPont. 2023. DuPont™ Kalrez® Perfluoroelastomer Parts: In Energy/ Oil & Gas. KZE-A40128-00-B0123 CDP.

DuPont. 2021. DuPont™ Kalrez® OG193 Perfluoroelastomer Parts: For Oil and Gas Applications Requiring High Rapid Gas Decompression (RGD) Resistance in a Broad Range of Temperatures, Conditions and Part Configurations. KZE A40087 00 B0921.

Fluorocarbon O-Ring, 95 Shore A, Oil & Gas Applications (Prädifa Series V1238-95). Available online at: <https://ph.parker.com/us/en/product-list/fluorocarbon-o-ring-95-shore-a-oil-gas-applications-praedifa-series-v1238-95?facet:4099276460822254724791051083238327197115,4099276460822254724791051083297110100327197115&productBeginIndex:0&facetLimit:&orderBy:&pageView:list&minPrice:&maxPrice:&pageSize:&loadProductsList:true&>. Retrieved June 7, 2023.

Habonium. 2018. Three piece ball valves. 04/18 REV2.04.

Kalrez® Parts in Natural Gas Sampling Systems and Delivery. 2023. Available online at: <https://www.dupont.com/knowledge/natural-gas-delivery.html>. Retrieved June 7, 2023.

Korzeniowski S et al. 2022. A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management. 19 (2): 326-354.

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McKeen M. 2017. Film Properties of Plastics and Elastomers. Fourth Edition. William Andrew.

Uschold, R. E. 1985. Fluoroelastomers: Today's Technology and Tomorrow's Polymers. Polymer Journal. 17(1): 253-263.

Viton™ Fluoroelastomers for Oil and Gas Exploration and Production. 2023. Available online at: <https://www.viton.com/en/industries/oil-gas>. Retrieved June 7, 2023.

FFKM (TFE-PMVE perfluoroelastomer)

Trade names include: Kalrez, Markez, perfluoroelastomer, AFLAS FFKM

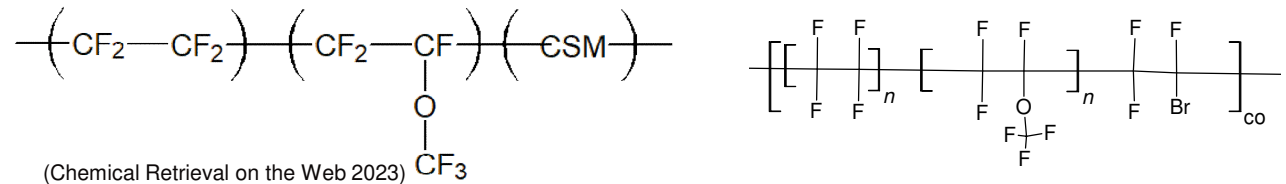
- Uses in the O&G industry: (primarily used in fluid sealing environments)**

- O-rings
- Mechanical and pipeline seals
- Pumps
- Compressors
- Christmas Trees
- Pipeline Valves/Ball valves
- Subsea Equipment
- Risers
- Monitoring/logging equipment
- Packers/packing elements
- (DuPont 2023; 2021; Kalrez Parts 2023)

- Benefits of this fluoropolymer:**

- Resistant to over 1500 chemical substances
- Service temperature up to 316°C (600°F)
- Excellent performance as static or dynamic seals
- Retains resilience and low compression set
- Good creep resistance
- Outperforms metals, FKM, PTFE, and other elastomers
- (McKeen 2017; DuPont 2023)

- Development:** Introduced in the mid-1970's (Uschold 1985; Byrdson 1994)



(Chemical Retrieval on the Web 2023)

Fully fluorinated class of elastomers that are typically made up of tetrafluoroethylene (TFE), a perfluoro (alkyl vinyl ether; PAVE), and a cure site monomer(s) (CSM) (Korzeniowski et al. 2022)

		Kalrez® Grades						
		OG193	0090	7390	7375	6375	0040	3065
		Chemicals						
Well stimulation & EOR	Steam, 204 °C	Best	Best	Best	Best	Best	Not suggested	Best
	Steam, 225 °C	Suitable	Suitable	Best	Best	Suitable	Not suggested	Suitable
Corrosion inhibitors	Ethylene Diamine, 90 °C	Best	Best	Best	Best	Best	Suitable	Best
	Morpholine	Best	Best	Best	Best	Best	Best	Best
Drilling fluids	Water based	Best	Best	Best	Best	Best	Suitable	Best
Brines	Brines ASTM D1141, 204 °C	Best	Best	Best	Best	Best	Suitable	Best
Formates	Cesium formates / water	Best	Best	Best	Best	Best	Suitable	Best
Well interventions	Hydrochloric acid	Best	Best	Best	Best	Best	Best	Best
Sour environment	Hydrogen sulfide (H ₂ S)	Best	Best	Best	Best	Best	Suitable	Best
Inhibitor	Methanol	Best	Best	Best	Best	Best	Best	Best
Hydrocarbons	Various	Best	Best	Best	Best	Best	Best	Best
		Application requirements						
Extrusion resistance / high pressure		Best	Best	Best	Not suggested	Not suggested	Not suggested	Best
High temperature, above 250 °C		Not suggested	Not suggested	Best	Best	Suitable	Not suggested	Suitable
Low temperature		Suitable	Not suggested	Not suggested	Not suggested	Not suggested	Best	Not suggested
RGD resistance, CO ₂		Best	Best	Not suggested	Not suggested	Not suggested	Not suggested	Not suggested
Electrical insulation		Not suggested	Not suggested	Not suggested	Best	Not suggested	Not suggested	Not suggested

(DuPont 2023)

FFKM (TFE-PMVE perfluoroelastomer)

Trade names include: Kalrez, Markez, perfluoroelastomer, AFLAS FFKM

References:

Chemical Retrieval on the Web. 2023. "FFKM - PERFLUOROELASTOMERS". <https://polymerdatabase.com/Elastomers/FFKM.html>. Accessed June 2023.

DuPont. 2023. DuPont™ Kalrez® Perfluoroelastomer Parts: In Energy/ Oil & Gas. KZE-A40128-00-B0123 CDP.

DuPont. 2021. DuPont™ Kalrez® OG193 Perfluoroelastomer Parts: For Oil and Gas Applications Requiring High Rapid Gas Decompression (RGD) Resistance in a Broad Range of Temperatures, Conditions and Part Configurations. KZE A40087 00 B0921.

Kalrez® Parts in Natural Gas Sampling Systems and Delivery. 2023. Available online at: <https://www.dupont.com/knowledge/natural-gas-delivery.html>. Retrieved June 7, 2023.

Korzeniowski S et al. 2022. A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management. 19 (2): 326-354.

McKeen M. 2017. Film Properties of Plastics and Elastomers. Fourth Edition. William Andrew.

Brydson J. A. 1994. Specialty Rubbers. Smithers Rapra.

Uschold, R. E. 1985. Fluoroelastomers: Today's Technology and Tomorrow's Polymers. Polymer Journal. 17(1): 253-263.

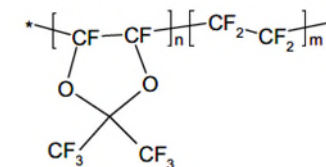
Specialty

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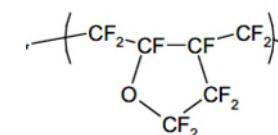
Amorphous fluoropolymers

Trade names include: Teflon AF, Cytop, Hyflon-AD

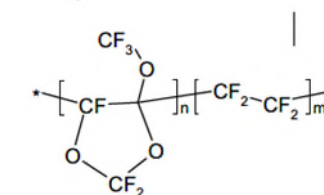
- **Uses in the O&G industry:**
 - Fluoropolymer - coated membranes used for separation of non-aqueous liquid (e.g., deep desulfurization of gasoline and diesel, H₂ recovery in refineries) (Liu and Tang 2009)
- **Benefits of this fluoropolymer:**
- Chemical stability, thermal stability, optical clarity, high gas permeability (Korzeniowski et al. 2022)
- **Development:**
 - Pre-1980s, all industrial fluoropolymers were semicrystalline. DuPont and Asahi Glass developed amorphous perfluoropolymers in the mid-1980s (Teng 2012).



Teflon AF



Cytop



Hyflon AD

(Teng 2012)

References:

Korzeniowski S et al. 2022. A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integrated Environmental Assessment and Management. 19 (2): 326-354.

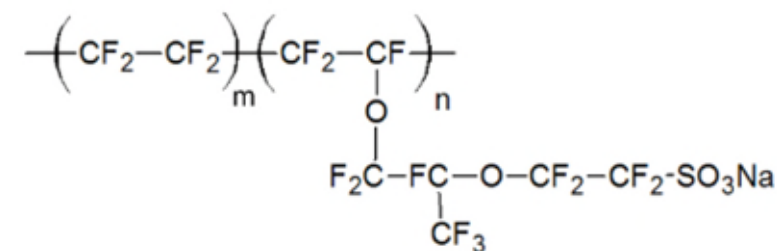
Liu, C and M-W Tang, inventors; Honeywell UOP, assignee. FLUOROPOLYMER COATED MEMBRANES. United State Patent US 2009/0277837 A1. 12 Nov 2009.

Teng, H. 2012. Overview of the Development of the Fluoropolymer Industry. Applied Sciences. 2, 496-512.

Fluorinated ionomers

Trade names include: Nafion, Fumapem, Flemion, Aquivion, Aciplex

- **Uses in the O&G industry:**
 - No specific uses identified
- **Benefits of this fluoropolymer:**
- Highly conductive (most applications of perfluorinated ionomers involve the passage of an electric current, in the form of cations, through the ionomer)
 - Form impermeable membranes
- **Development:**
 - Developed in the 1960s and are critical to the chlor-alkali and fuel cell industries (Grot 2011)

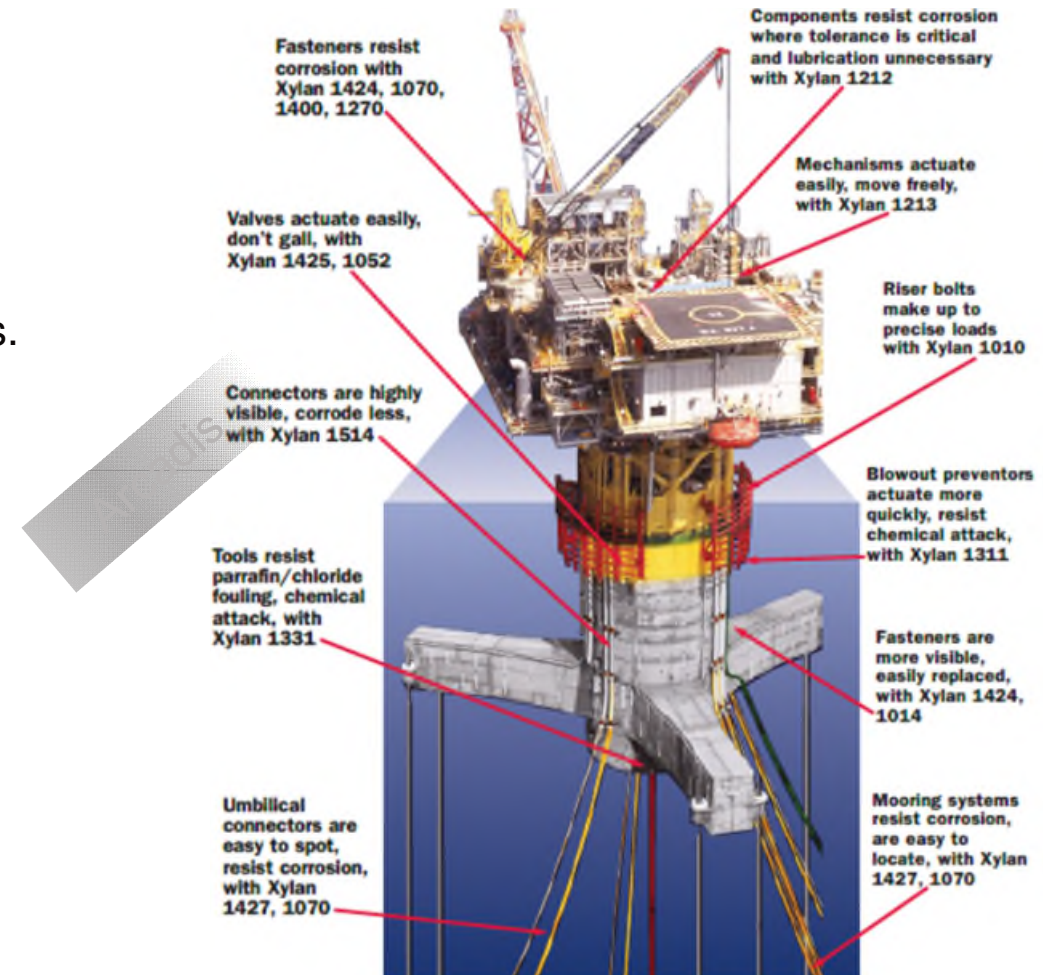


Nafion (Chemical Retrieval on the Web 2023)

Xylan - Off-Shore Oil Applications

Xylan is a brand-name fluoropolymer coating line developed by the Whitford Worldwide Company, now owned by PPG.

- Xylan coatings are composed of fluoropolymers such as PTFE, PFA, and FEP, combined with reinforcing binder
- **Uses in the O&G industry:**
 - Widely used in the off-shore oil industry for a variety of applications such as bolts, fasteners, valves and connectors.
- **Benefits of this fluoropolymer:**
 - Chemical and corrosion resistance
 - Excellent weather resistance
 - High heat resistance
 - UV resistance
 - Wear resistance
- **Development:**
 - First manufactured by the Whitford Worldwide Company in 1969



Research Findings:

Standards that Identify Fluoropolymers

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D1418-22 Standard Practice for Rubber and Rubber Latices—Nomenclature Viton

D3307-21 Standard Specification for Perfluoroalkoxy (PFA) Resin Molding and Extrusion Materials

D3222-21 Standard Specification for Unmodified Poly(Vinylidene Fluoride) (PVDF) Molding Extrusion and Coating Materials

D6867-19 Standard Specification for Perfluoroalkoxy (PFA)-Fluoropolymer Tubing

D7471-19 Standard Specification for CPT-Fluoropolymer Molding and Extrusion Materials

D8436-22 Standard Specification for Fluoropolymer-based Materials for Use for Encapsulation of Downhole Cable (PFA, ETFE, ECTFE, FEP)

D5575-18 (2023) Standard Classification System for Copolymers of Vinylidene Fluoride (VDF) with Other Fluorinated Monomers

D1710-15(2021) Standard Specification for Extruded Polytetrafluoroethylene (PTFE) Rod, Heavy Walled Tubing and Basic Shapes

D6713-21 Standard Specification for Extruded and Compression Molded Shapes Made from Poly(Vinylidene Fluoride) (PVDF)

D8366-21a Standard Specification for Extruded and Compression Molded Shapes Made from Unfilled Poly(Vinylidene Fluoride) PVDF

D3295-20 Standard Specification for PTFE Tubing, Miniature Beading and Spiral Cut Tubing

D3595-14(2019)e1 Standard Specification for Polychlorotrifluoroethylene (PCTFE) Extruded Plastic Sheet and Film

ASTM continued...

D4745-19 Standard Classification System and Basis for Specification for Filled Polytetrafluoroethylene (PTFE) Molding and Extrusion Materials Using ASTM Methods

D4894-19 Standard Specification for Polytetrafluoroethylene (PTFE) Granular Molding and Ram Extrusion Materials

F477-14 2021 Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe

D7472-19 Standard Specification for EFEP-Fluoropolymer Molding and Extrusion Materials

D3296-14a(2019) Standard Specification for FEP-Fluorocarbon Tube

D1710-15(2021) Standard Specification for Extruded Polytetrafluoroethylene (PTFE) Rod, Heavy Walled Tubing and Basic Shapes

D3159-22 Standard Specification for Modified ETFE Fluoropolymer Molding and Extrusion Materials

D3308-12(2022) Standard Specification for PTFE Resin Skived Tape

D6585-17(2022) Standard Specification for Unsintered Polytetrafluoroethylene (PTFE) Extruded Film or Tape

D7193-17(2022) Standard Specification for Unsintered Pigmented Polytetrafluoroethylene (PTFE) Extruded Film or Tape

D3294-22 Standard Specification for Polytetrafluoroethylene (PTFE) Resin Molded Sheet and Molded Basic Shapes

D7211-23 Standard Specification for Parts Machined from Polychlorotrifluoroethylene (PCTFE) and Intended for General Use

D3275-18(2023) Standard Classification System for E-CTFE-Fluoroplastic Molding, Extrusion, and Coating Materials

D4895-18(2023) Standard Specification for Polytetrafluoroethylene (PTFE) Resin Produced From Dispersion

ISO 23936-2:2011 Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 2: Elastomers

ISO 10423:2022 Petroleum and natural gas industries — Drilling and production equipment — Wellhead and christmas tree equipment
(This document supplements API Spec 6A, 21st edition (2018), the requirements of which are applicable with the exceptions specified in this document.)

ISO 13628-4:2010 Petroleum and natural gas industries — Design and operation of subsea production systems — Part 4: Subsea wellhead and tree equipment

ISO 13628-10:2005 Petroleum and natural gas industries — Design and operation of subsea production systems — Part 10: Specification for bonded flexible pipe for petroleum and natural gas industries

ISO 13628-15:2011 Petroleum and natural gas industries — Design and operation of subsea production systems — Part 15: Subsea structures and manifolds

ISO 10400:2018 Petroleum and natural gas industries — Formulas and calculations for the properties of casing, tubing, drill pipe and line pipe used as casing or tubing

ISO 11960:2020 Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells

ISO 13678:2010 Petroleum and natural gas industries — Evaluation and testing of thread compounds for use with casing, tubing, line pipe and drill stem elements

ISO 15463:2003 Petroleum and natural gas industries — Field inspection of new casing, tubing and plain-end drill pipe

ISO 27914:2017 Carbon dioxide capture, transportation and geological storage — Geological storage

ISO 27916:2019 Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO₂-EOR)

API Spec 6A, 21st edition (2018), *Specification for Wellhead and Tree Equipment*

API Spec 14A, Petroleum and natural gas industries — Downhole equipment — Subsurface safety valve equipment

API Spec 17D, 2nd edition (2011), Design and Operation of Subsea Production Systems — Subsea Wellhead and Tree Equipment

Additional mentions of fluoropolymers: 16A, 17B, 17F, 17J, 17TR1, 17TR8, 19D, 21TR1, 5C1, 5C5, 5CT, 6FA, 6J, 15S, 551, 553, 574, 584, 588, 608, 610

Final Notes

Arcadis

Potential Alternatives/ New Directions

Nanofillers are being studied to improve the wear of PTFE in the form of PTFE nanocomposites (Ye et al. 2013).

HDPE can be used as a substitute for PVDF pipe liners but is more prone to failure under high pressure (Khalid et al. 2020).

Polyamides (PA11 And PA12) can also be used as pipe liners in similar applications to PVDF (Khalid et al. 2020).

New 'superhydrophobic' coatings for oil and gas pipelines have been developed in the past three years to address oil and gas pipeline explosions. While the coatings are polymer based, it is unclear if they contain any fluorinated polymers (Ijaola et al. 2020).

PEEK (polyetheretherketone) is a non-fluorinated polymer that has widespread applications in the oil and gas industry and can be used as an alternative to fluorinated compounds (deLeon et al. 2021).

HDPE-based products that contain nano ceramic or nano aluminum oxide (Micro Powders, 2021) and polyurethane (PU), polyvinyl chloride (PVC), polyolefin and epoxy powders for coating materials (OECD 2022).

Hydrogenated nitrile butadiene rubber (HNBR) for fluoroelastomers (Viton-FKM) (New Deal Seals).

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Current Scientific Consensus Indicates that Solid Fluoropolymers are Polymers of Low Concern

Korzeniowski et al. 2022:

- *“The data presented demonstrate the fluoropolymers in the study are thermally, biologically, and chemically stable, negligibly soluble in water, nonmobile, nonbioavailable, nonbioaccumulative, and nontoxic, and contain low levels of impurities.”*

Henry et al. 2018:

- *“Data show that fluoropolymers have thermal, chemical, photochemical, hydrolytic, and biological stability.”*
- *“The data presented demonstrate that the fluoropolymer class of PFAS is well defined, meets PLC criteria, and should be considered as distinctly different from other classes of PFAS.”*

But See:

Myers et al., 2014: Thermal decomposition fragments of fluoropolymers (PCTFE e.g.) might be environmentally persistent and toxic.

Lohmann et al. 2020:

- *“The concerns we present above suggest that there is no sufficient evidence to consider fluoropolymers as being of low concern for environmental and human health. The group of fluoropolymers is too diverse to warrant a blanket exemption from additional regulatory review. Their extreme persistence and the emissions associated with their production, use, and disposal result in a high likelihood for human exposure as long as uses are not restricted. Concluding that some specific fluoropolymer substances are of low concern for environmental and human health can only be achieved by narrowly focusing on their use phase, as was done by Henry et al.”*

References:

Henry, B. J.; Carlin, J. P.; Hammerschmidt, J. A.; Buck, R. C.; Buxton, L. W.; Fiedler, H.; Seed, J.; Hernandez, O. A Critical Review of the Application of Polymer of Low Concern and Regulatory Criteria to Fluoropolymers. *Integr. Environ. Assess.Manage.* 2018, 14 (3), 316– 334, DOI: 10.1002/ieam.4035.

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Questions?