THE USE OF PFAS IN CHEMICAL PLANT EQUIPMENT

AN INVENTORY STUDY

Final Report

September 2023

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Executive Summary (1/4)

Background and methodology

- In May 2023, Cefic contracted Accenture to conduct a thorough **mapping of uses of PFAS in chemical industry manufacturing equipment** and to investigate the **use and the availability of potential alternatives**, as well as **waste management practices**
- To obtain a quantitative inventory, **a detailed list of equipment types used in chemicals plants was compiled**. Collaborating with Cefic members, **a tailored survey comprising over 600 questions was developed**. The objective was to obtain a detailed overview of the presence of PFAS in different equipment types, reasons for their use, where alternatives were available and how long it would take to develop and/ or implement alternatives to PFAS. Via the survey and individual interviews, companies were also asked to describe current waste management systems related to PFAS-containing equipment
- **To complement the quantitative survey and qualitative interviews, advanced analytics were applied**, looking into data from business and industry journals, industrial equipment product data, and Material Safety Data Sheets (for PFAS and their potential alternatives). This was **followed by an analysis of PFAS-based patents** relevant to chemical plants

Coverage of the study

- This report represents **111 Cefic member companies, covering 1421 plants in Europe**, who responded to the survey. More than 50 one-on-one interviews with companies, industry associations and chemical equipment suppliers were conducted
- **More than 1 million articles from technical journals and additional sources were screened** for PFAS-relevant information
- In the patent analysis, **a total of 166 000 filings within the chemical segments were examined**, of which 52 000 were identified as being specifically related to PFAS-based application-focused innovation

Executive Summary (2/4)

Results

Which PFAS are used and in which type of equipment?

- The findings indicated that **the surveyed companies all use most of the equipment listed in the survey**
- In addition, they reported an **extensive PFAS usage across their (core) equipment**. Seals, coatings and valves were the main PFAS-containing components. This was corroborated by the additional advanced analytics
- **Fluoropolymers (in solid form) were most commonly reported** (gaskets, seals), but there were also **examples of non- fluoropolymer solids and several PFAS in liquid and gaseous forms**. Once again, these findings were further validated by the advanced analytics exercise

Why are PFAS used in chemical plants?

- **Performance, due to their unique set of combined properties, and safety requirements are reported as the main factors driving the use of PFAS** in equipment
- Performance of the equipment components is leading, composition of the product is usually less or not known or not specified in the data sheets
- Properties that are commonly mentioned are chemical resistance, temperature resistance, mechanical strength, low coefficient of friction, non-flammability, water resistance and electrical resistance. It is the **unique combination of several of these properties** that explains the use of PFAS

Executive Summary (3/4)

The challenge of substitution

- The survey and **literature research** revealed that **for some equipment, such as membranes and diaphragms, no alternatives have been identified to date** and identifying them will be very challenging due to the required combination of properties
- **Some substitutes have been identified for specific use cases,** although many have clear **limitations**, such as restricted use conditions (temperature limits, less corrosion resistance, lower safety levels,…)
- Patent analysis revealed that, **since 2018, PFAS-based innovation activities have been declining**, especially in Europe
- When **reporting on their search for alternatives, study participants noted the following challenges**:
  - The low likelihood of having **the same persistence characteristic for alternative materials** with similar properties to PFAS, **and risk or regrettable substitution**
  - Possibility of a **negative impact on safety** of future installations and workers
  - The **alternative development process is long**, having to go through R&D, testing, client approval, …
  - A **lack of confidence in the ability of alternatives-based equipment suppliers to provide guarantees** for the same level of performance, safety, sustainability by design and fitness for a circular economy
  - The **supply chain not being ready** to cope with a sharp increase in demand of their alternatives
  - Some **potential alternatives contain traces of PFAS** (voluntarily or involuntarily)
- In terms of timeline, companies estimate that when technical alternatives have been identified, **the timing to replace PFAS-containing equipment is estimated to be above 10 years**. This is due to the length of maintenance cycles, plant renewals, investments, validity testing, …

Executive Summary (4/4)

PFAS waste management

- On top of the generic waste management measures employed when equipment reaches its end of life, some companies have reported **specific management plans related to PFAS**. These include:
  - Periodic **recycling** and organized **recovery** of certain gaseous PFAS
  - **Incineration** or **recycling** of lubricants and greases
  - **Incineration** or **recycling** of solid PFAS, in addition to some remaining landfilling of non-hazardous waste
- Some companies declared working on additional PFAS-specific waste management plans

Impact of the proposal to restrict PFAS on the chemical industry as a PFAS equipment user

- The chemical industry is highly **CAPEX** (Capital Expenditure) **intensive** and operates at **high health, safety, security and environmental standards** (HSSE). The unique properties of PFAS containing components are essential for these operations
- If PFAS use is banned in industrial equipment and alternatives are available, companies estimate:
  - **Maintenance expenditure to increase 2 to 3 times** versus the baseline
  - **Potential temporary shutdown of plants of 6 months to 2 years**, to adapt installations
  - **20 to 50% of plants will need to be rebuilt**, entailing CAPEX requirements
  - **Lost revenues due to client requalification of processes** taking from 6 months up to 2 years
  - **Higher CAPEX** and **increased maintenance cost** in **new investments**
- Overall, the proposed restriction on the use of PFAS, including within chemical plant equipment, is expected to have serious **implications on the operations of existing assets and on decisions to invest in new ones**. These impacts range from the total shutdown of manufacturing facilities to the cessation of key strategic materials production, as well as a shift to other geographies for new investments

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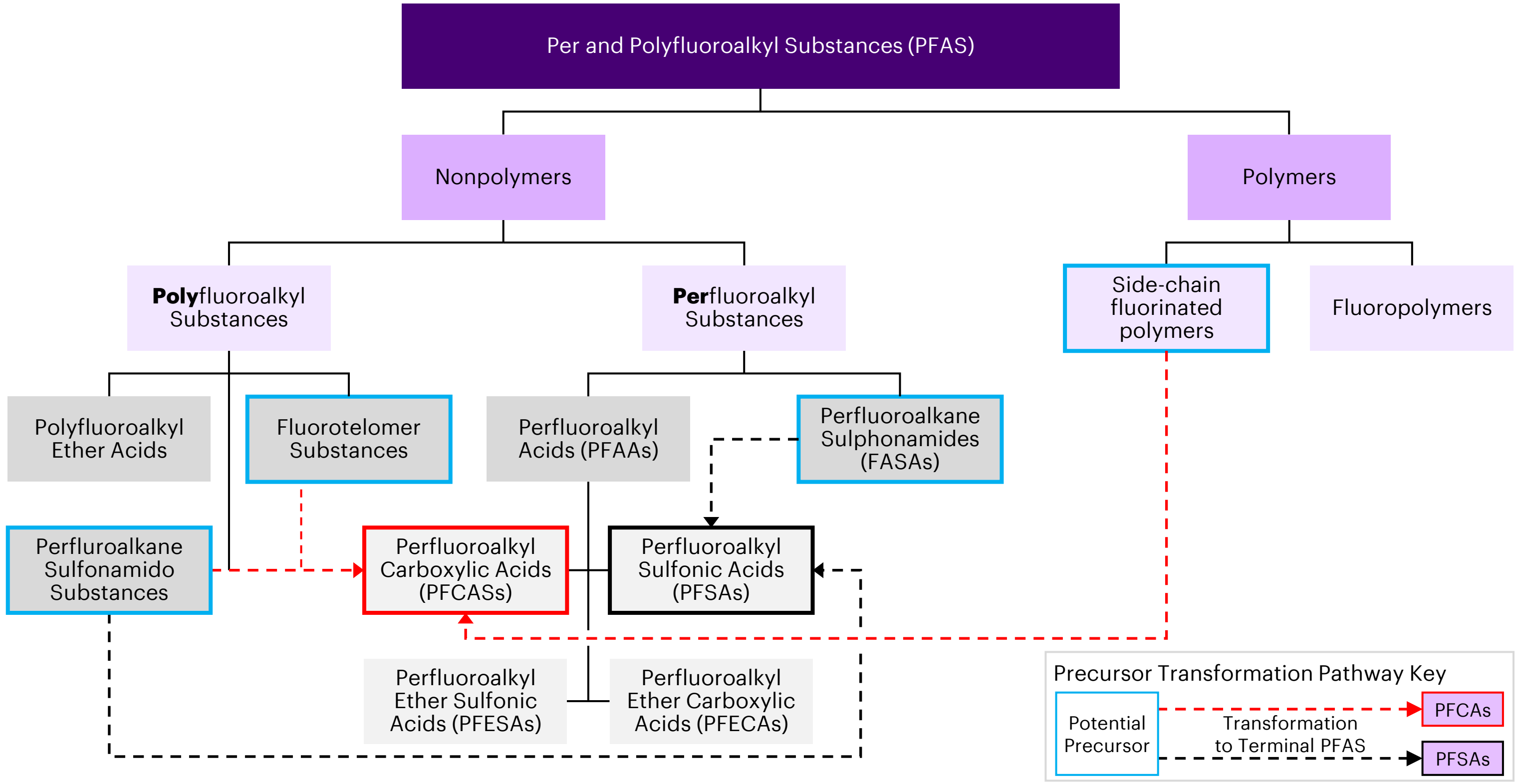
What are PFAS?

PFAS are a large group of substances, both polymeric and non- polymeric, containing a Carbon-Fluorine bond

Key elements

F	Derivatives of **fluorinated** compounds: • F_2 • HF • $ClF_2C\text{-}C\text{-}F_2Cl$ • CH_3CF_2Cl • $CHClF_2$
C-F	Bond heavily resistant to degradation

PFAS product tree (simplified)*



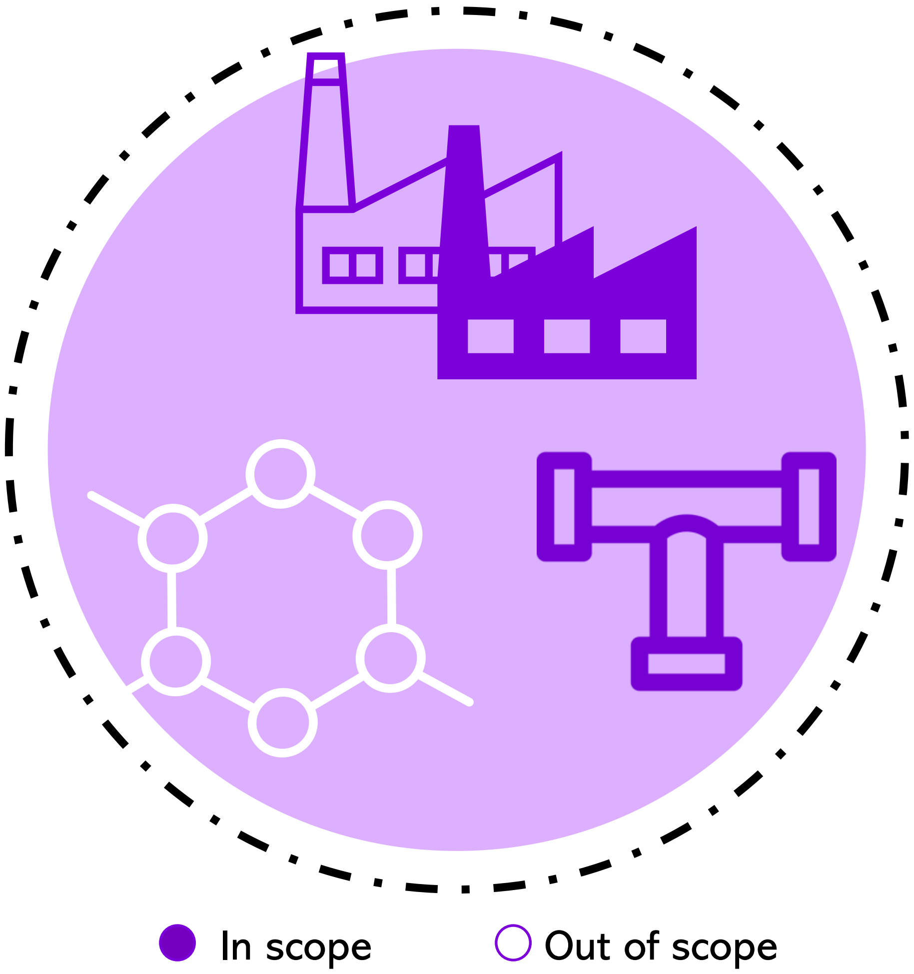
Sources: * SFEI, OECD, Accenture research

What was the scope of the study?

The study focused exclusively on the use of PFAS in chemical plants equipment

Focus of the study

- The study focused on investigating **the presence of PFAS within equipment used in chemical plants and the potential implications of a restriction**
- The production of PFAS as a chemical element was not in the scope of the study



What was the approach to the study?

The report is based on chemical companies' survey responses and interviews, combined with advanced analytical methods* that are text mining and patent analysis, and Accenture's analysis of plant equipment containing PFAS as a key component process

Scope of the study

The study aimed to:

- **Identify** the equipment containing PFAS in chemical plants
- **Identify** the different types of PFAS used in chemical plant equipment and their properties
- **Explore** potential alternatives to PFAS in the affected equipment
- **Enquire** about best practices related to PFAS management
- **Assess** the expected impacts of a ban on the use of PFAS in industrial equipment

Methodology

- Listing of segments of the chemical manufacturing process
- Development of a survey questionnaire to investigate PFAS uses, including **600+ questions covering 30+ categories of equipment,** optimized with Cefic members
- **Survey of 111** companies (**1421 plants**), representing the diverse European chemical industry landscape
- **50+ interviews** conducted with **CEFIC members, industries associations** and **chemical equipment suppliers** (joints/gaskets, piping, valves, refrigerant gas, paint/coating, electronics)
- **Use of advanced analytics through** text mining, MSDS (Material Safety Data Sheet) analysis and patent analysis

*Generative artificial intelligence methods

What was the approach to the study?

Interviews have been conducted with stakeholders from the whole industry to determine the impact of a ban on operations

Diversity of interviewee profiles	Deep dive interviews	Workshops
• Interviews have been conducted with **voluntary chemical industry players**, including: – **Chemical companies** – **National associations** – **Suppliers** (joints/gaskets, piping, valves, refrigerant gas, paint/coating, electronics)	• **Focus on** – Industry representatives' **maturity in PFAS management** – **Ability of stakeholders to identify PFAS** in chemical plant equipment – **Waste management programs** – existing and/or upcoming	• **Two sets** of workshops with ~**25 experts** of **10 companies** to gather data on selected chemical plants and refineries: – **Inventory of industrial equipment containing PFAS**, their **alternatives** and emissions, waste and HSE **management plans in place** – Analysis of **operational, economic, social and environmental impact** of a PFAS ban

Source: Accenture analysis of questionnaire

What was the approach to the study?

The scope and structure of the survey, specifically created for the study, allowed to capture a picture of PFAS' presence in chemical plants in Europe

Divided into various sections

- **Respondent profile**
- **Company plans regarding PFAS**
- **PFAS usage in chemical plants**
  - **Process unit equipment** – including environmental protection equipment (wastewater treatment, gas purification unit)
  - **Safety and protection equipment**
  - **Power and utilities equipment**
  - **Other Equipment**
  - **Other products** (greases, lubricants, catalysts, refrigerants, processing/auxiliary aids linked to the equipment)

For each usage reason, **substitution strategy**

Several types of questions

- **Different type of questions, including Yes/No, multiple choice, free text**
- The **multiplicity of question types** allowed to **gather as much detail and precision as possible** for each topic and equipment
- **Deep dive on each equipment** via a loop of several questions

Geographical scope

- **Plants located in Europe (EEA)**

Source: Accenture questionnaire

What was the approach to the study?

Article and Material Safety Data Sheet (MSDS) analysis through advanced analytics complemented data from the companies

ARTICLE ANALYSIS

Focus on two types of data	Main data sources
Data from Business and Industry journal articles	– **Factiva data set,** from which **833 661 articles were screened** from various sources ranging from *Chemicals & Chemistry, Coatings World, Specialty Chemicals, Journal of Engineering, etc.* – **Lexis-Nexis data set,** from which **262 407 articles were collected and screened** from several sources including *Chemistry World.com, Journal of the American Chemical Society, Chemicals Monitor Worldwide, Chemical News and Intelligence, Wiley: Chemistry – A European Journal, etc.*
Industrial equipment product data	

Methodology

Analysis of articles from 2021/01/01 till 2023/05/10

- Each article was screened against a **key list of PFAS names** (139 names) and **chemical equipment names** (400 names)
- Only articles that contained both PFAS names and chemical equipment names were considered for further analysis
- As a result, **2049 articles come Lexis-Nexis and 4728 articles Factiva were selected and analyzed by GPT-3*** to verify PFAS names, and chemical equipment, and to also identify the application of PFAS

MSDS ANALYSIS

Methodology

Chemicals comparison and fact-based mapping of PFAS alternatives

- Analysis built on **all publicly available datasheets** and ingestion of the data into a cloud-based analytics tool
- Comparison of chemicals along all technical parameters available in datasheets, typically **30-50 parameters**
- Establishment of an **up-to-date list of relevant PFAS alternatives for specific performance characteristics** in chemicals

*Source: Accenture text mining analysis, *Generative AI language predictive model, Accenture Material Safety Data Sheet analysis*

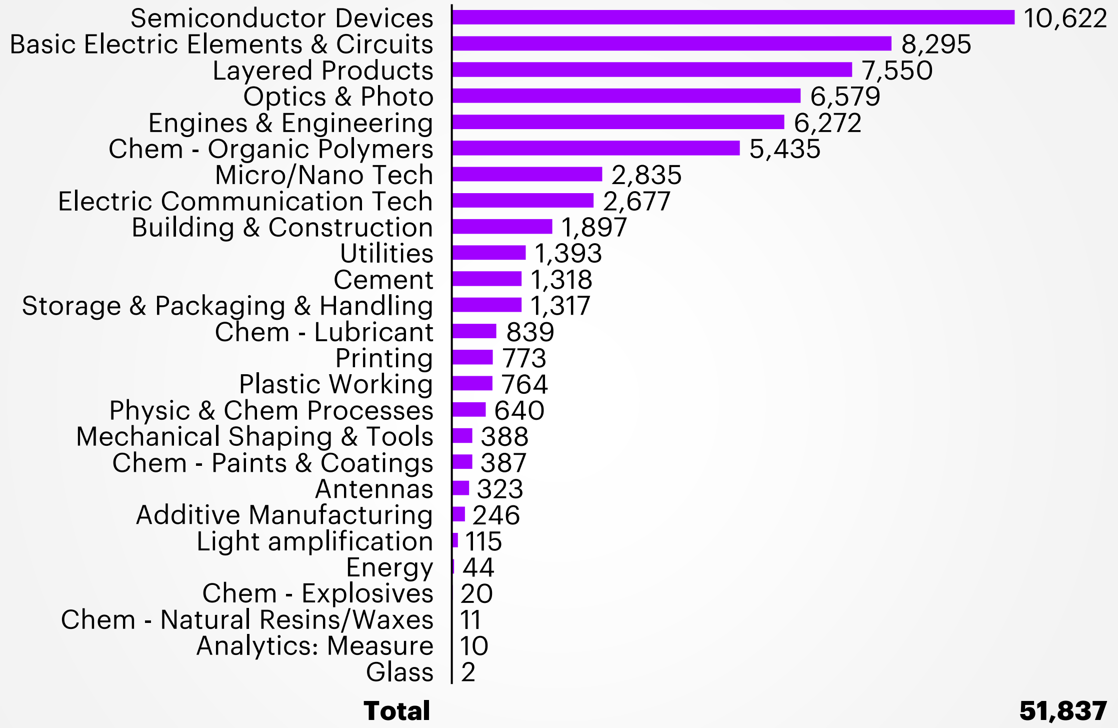
What was the approach to the study?

Further, an analysis of patents relevant to chemical plants was conducted, focusing on patents filed in relation to PFAS applications from the last two decades

Methodology

- The analysis encompasses patent applications filed between **2010 to 2021**
- During this time frame, a total of **166K filings within chemical segments** have been examined
- Identifying patents specifically related to application-focused innovation, **52K priority filings** have been pinpointed
- The subsequent segments, which are not relevant within the context, have been excluded:
  - Agro, Aircraft, Automotive, Batteries, Biotech, CG&S, Chem – Agrochem, Chem – Healthcare, Cosmetics & Toiletries, Cycles, Food & Beverages, Health, Marine & Transport, Mining, Rail & Transport, Space Vehicles, Textile & Leather, Tires, Weapons, Wood & Paper

Chemical segments in the 52k priority filings were pinpointed



Source: Accenture Research based on DerwentInnovation™(Clarivat) e©,2023; Analysis based on set 166K patents relevant to chemical equipment filled between 2010 and 2021

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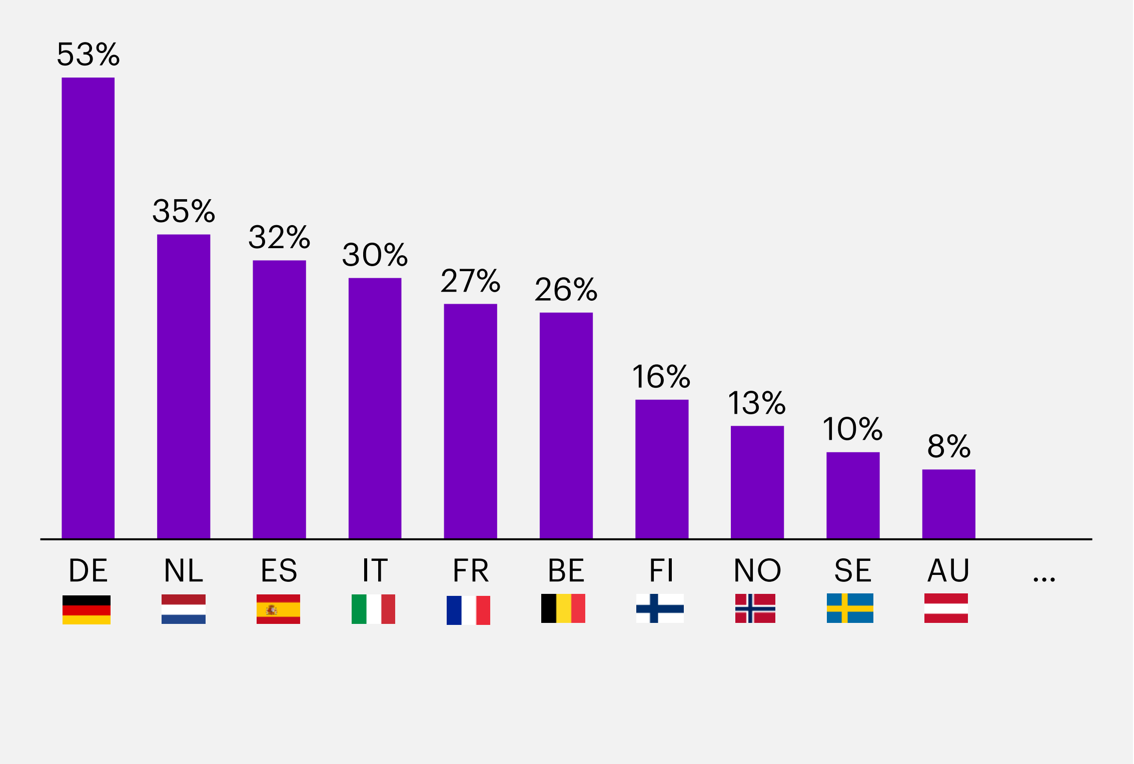
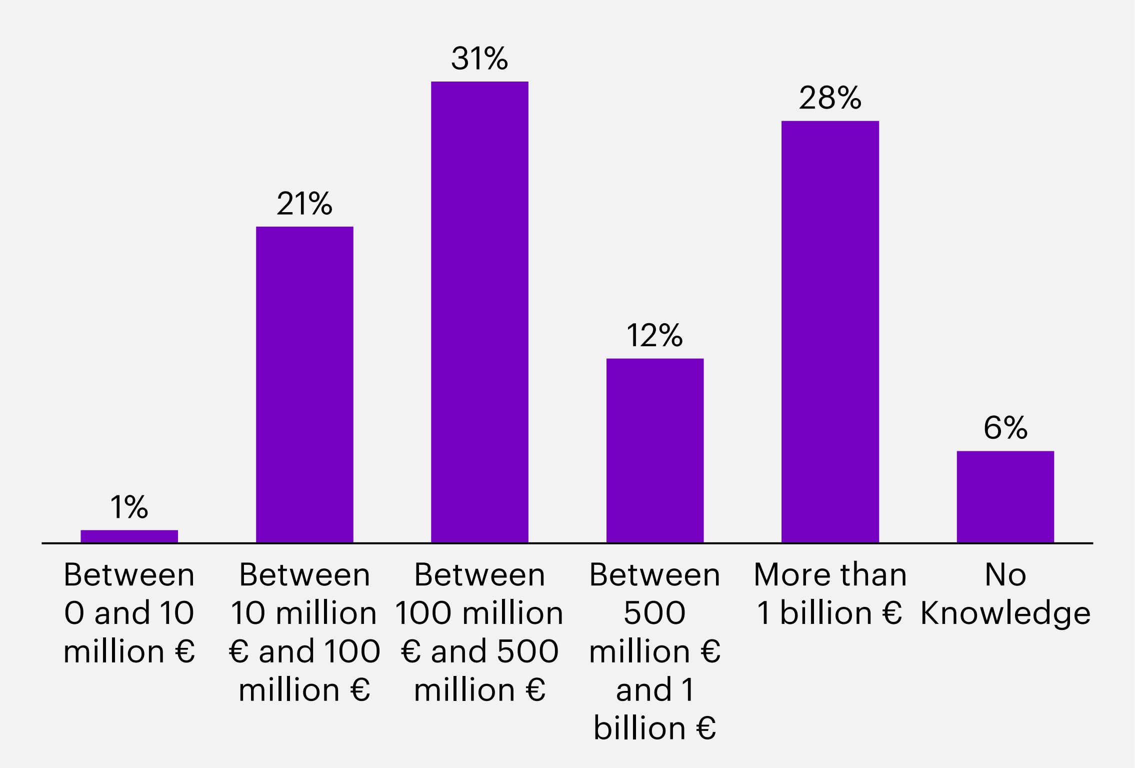
Who responded to the survey?

1421 plants from across Europe were covered, including companies of all sizes - totaling to more than 50 billion € in turnover

% of respondents having plants in a specific country



% of respondents by turnover of the plants covered



Source: Accenture analysis of questionnaire

Who responded to the survey?

The main sectors of the broad chemical industry participated

B.08 : Other mining and quarrying
- Extraction of salt

C.17 : Manufacture of paper and paper products
- Manufacture of pulp

C.21 : Manufacture of basic pharmaceutical products and pharmaceutical preparations
- Manufacture of basic pharmaceutical products
- Manufacture of basic pharmaceutical products and pharmaceutical preparations
- Manufacture of pharmaceutical preparations

C.24 : Manufacture of basic metals
- Aluminum production
- Lead, zinc and tin production
- Manufacture of basic precious and other non-ferrous metals

C.28 : Manufacture of machinery and equipment
- Manufacture of fluid power equipment

G.46 : Wholesale trade, except of motor vehicles and motorcycles
- Other specialized wholesale
- Wholesale of chemical products
- Wholesale of solid, liquid and gaseous fuels and related products

G.47 : Retail trade, except of motor vehicles and motorcycles
- Retail sale of automotive fuel in specialized stores

Source: Accenture analysis of questionnaire

C.10 : Manufacture of food products
- Manufacture of homogenized food preparations and dietetic food
- Manufacture of other food products

C.19 : Manufacture of coke and refined petroleum products
- Manufacture of coke oven products
- Manufacture of refined petroleum products

C.22 : Manufacture of rubber and plastic products
- Manufacture of other plastic products
- Manufacture of other rubber products
- Manufacture of plastic plates, sheets, tubes and profiles
- Manufacture of plastics products

C.25 : Manufacture of fabricated metal products, except machinery and equipment
- Forging, pressing, stamping and roll-forming of metal; powder metallurgy
- Treatment and coating of metals

D.35 : Electricity, gas, steam and air conditioning supply
- Electric power generation, transmission and distribution
- Manufacture of gas; distribution of gaseous fuels through mains
- Production of electricity
- Steam and air conditioning supply

H.49 : Land transport and transport via pipelines
- Transport via pipeline

C.13 : Manufacture of textiles
- Manufacture of non-wovens and articles made from non-wovens, except apparel
- Manufacture of textiles
- Preparation and spinning of textile fibers

C.20 : Manufacture of chemicals and chemical products
- Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic rubber in primary forms
- Manufacture of chemicals and chemical products
- Manufacture of dyes and pigments
- Manufacture of explosives
- Manufacture of fertilizers and nitrogen compounds
- Manufacture of glues
- Manufacture of industrial gases
- Manufacture of man-made fibers
- Manufacture of other chemical products
- Manufacture of other chemical products
- Manufacture of other inorganic basic chemicals
- Manufacture of other organic basic chemicals
- Manufacture of paints, varnishes & similar coatings, printing ink & mastics
- Manufacture of perfumes and toilet preparations
- Manufacture of pesticides and other agrochemical products
- Manufacture of plastics in primary forms
- Manufacture of soap and detergents, cleaning and polishing preparations
- Manufacture of synthetic rubber in primary forms

M.72 : Scientific research and development
- Research & experimental development on natural sciences & engineering
- Scientific research and development

What were the challenges?

Companies of all sizes found it challenging to map uses of PFAS in industrial equipment in a relatively short timeframe

Focus on equipment performance

- Equipment and material selection prioritize **equipment performance** linked to **functional specification** such as thermal, pressure and chemical compatibility needs
- **Regulatory teams** primarily focus on assessing the **compliance and safety** of raw materials utilized in the production process
- The diversity of teams, including maintenance teams, within a company due to a **high number of plants and their varied locations makes it difficult to centralize knowledge of PFAS presence**
- Involvement of **external third parties** in equipment placement and maintenance creates a lack of awareness of the constitution of company's industrial assets

Widespread presence of various PFAS in many equipment

- **Multiple** and **different equipment** exist in a chemical plant
- PFAS are used in a **wide range** of equipment such as:
  - Pipes
  - Valves (Body, Washers & Gaskets)
  - Pumps (Coating & Gaskets)
  - Columns
  - Sensors
  - Instruments
  - ...

Source: Questionnaire and interviews of chemical companies and suppliers

Which equipment was investigated ?

Below is an illustration of chemical plant equipment:

Process Unit’s Equipment

	Agitators		Distillation Towers		Crystallizers
	Fans		Dryers		Mechanical Separators
	Conveyors		Evaporators		Reactors
	Cooling Towers		Fired Heaters		Refrigeration Systems
	Crushers		Gaskets & Sealings		Piping
	Pumps		Steam Injectors		Valves
	Instruments		Heat Exchangers		Vessels
	Couplings (Motors)		Grinders		Membranes

Source: List of illustration in appendix

Safety and Protection

	PPE		Firefighting Foams

Power and Utilities

	Power Supply		Cables & Wirings

Other Products

	Greases		Lubricants
	Catalysts		Refrigerants

Which equipment was investigated ?

The presence of PFAS components was studied across manufacturing processes

Level 1	Level 2			
Process units	Agitators	Devices for process control, Instruments	Heat exchangers	Vessels
	Compressors, Turbines, Fans	Distillation and Absorption towers	Mechanical separators	Other process units
	Conveyors	Dryers	Motors and Coupling	
	Cooling towers	Evaporators	Reactors	
	Crushers and Grinders	Fired heaters	Refrigeration systems	
	Crystallizers	Gaskets and Sealings	Piping	
	Pumps	Steam injectors and Vacuums	Valves and Accessories	**Level 3**
Safety and protection	PPE			Gloves, Lab coats, Face masks, Tapes, Sleeves, ...
	Plant safety equipment			Firefighting foams, ...
Power & utilities	Power supply			
	Cables and Wirings			
Other products	Greases	Catalysts	Processing, Auxiliary aids linked to equipment	
	Lubricants	Refrigerants		
Other equipment				

Source: Accenture research and analysis

Which equipment was investigated ?

The survey found that the companies surveyed have most of the equipment covered in this study...

Presence of equipment in the company		Yes	No knowledge	Potent. Presence of equipment*
Process Unit's Equipment	Agitators	97%	1%	98%
	Compressors	95%	3%	98%
	Turbines	76%	4%	81%
	Fans	95%	3%	98%
	Conveyors	94%	2%	96%
	Cooling towers	93%	0%	93%
	Process control devices	100%	0%	100%
	Grinders	79%	2%	81%
	Crystallizers	70%	7%	77%
	Device for process analysis	97%	1%	98%
	Instruments	97%	2%	99%
	Distillation towers	88%	2%	90%
	Absorption towers	86%	5%	91%
	Dryers	94%	3%	98%
	Evaporators	89%	4%	93%
	Fired heaters	87%	6%	93%
	Gaskets and Sealings	99%	0%	99%
	Gas purification units	86%	7%	93%
	Heat exchangers	96%	2%	98%
	Mechanical separators	90%	4%	94%
	Motors and Couplings	99%	0%	99%
	Reactors	96%	0%	96%
	Refrigeration systems	95%	4%	99%
	Piping	99%	0%	99%
	Pumps	100%	0%	100%
	Steam ejectors	86%	9%	95%
	Vacuum pumps	98%	1%	99%
	Valves and accessories	99%	0%	99%
	Vessels	98%	0%	98%
	Wastewater treatment	94%	2%	96%

- On average, **95%** of the companies have all selected **process unit's equipment** in their plants

Additional types of equipment were listed by companies in the survey:

- Isolators, hoses, incinerators, filling machines, containers, electrolyzers, membranes, diaphragms, nanofiltration, laboratory equipment, special vehicles

The percentage is based on the number of responses received per question for each equipment, which corresponds to the sum of the percentages of Yes and the percentages of No knowledge.
Source: Accenture analysis of questionnaire responses received.

In which equipment are PFAS present?

… and that PFAS is contained in nearly all of them

PFAS presence in equipment		Yes	No knowledge	Potent. PFAS*
Process Unit's Equipment	Agitators	61%	23%	84%
	Compressors	53%	34%	87%
	Turbines	30%	33%	63%
	Fans	41%	33%	74%
	Conveyors	43%	31%	75%
	Cooling towers	27%	37%	64%
	Grinders	31%	31%	62%
	Crystallizers	39%	21%	61%
	Process control devices	65%	29%	94%
	Devices for process analysis	62%	29%	91%
	Instruments	71%	25%	96%
	Distillation towers	56%	22%	78%
	Absorbtion towers	58%	22%	81%
	Dryers	52%	28%	80%
	Evaporators	45%	29%	74%
	Fired heaters	29%	33%	62%
	Gaskets and Sealings	91%	7%	98%
	Gas purification units	43%	33%	76%
	Heat exchangers	57%	26%	83%
	Mechanical separators	53%	26%	79%

PFAS presence in equipment		Yes	No knowledge	Potent. PFAS*
Process Unit's Equipment	Motors and couplings	40%	37%	77%
	Reactors	59%	19%	78%
	Refrigeration systems	68%	24%	92%
	Piping	76%	17%	93%
	Pumps	81%	18%	99%
	Steam ejectors	23%	41%	64%
	Vacuum pumps	58%	31%	89%
	Valves and accessories	87%	11%	98%
	Vessels	58%	16%	74%
	Wastewater treatment	43%	40%	83%
Safety & protection	PPE	58%	30%	89%
	Plant Safety Equipment	50%	35%	85%
Power & utilities	Power Supply Equipment	38%	42%	81%
	Plants Cable & Wiring Equipment	38%	44%	82%
Other products	Greases	39%	38%	78%
	Lubricants	42%	38%	80%
	Plants Catalysts	5%	25%	30%
	Refrigerants	64%	19%	83%
	Processing aids	15%	39%	55%

**Percentage based on the number of response received per question for each equipment*
Source: Accenture analysis of questionnaire

In which equipment are PFAS present?

Seals, coating and valves are the main PFAS containing components in chemical plant equipment

Major equipment components containing PFAS

PFAS presence in equipment		Seals (Gasket, O-ring)	Coating	Piping	Valves	Membranes
Process unit's equipment	Agitators	56%	16%		3%	
	Compressors	49%	2%		10%	
	Turbines	43%	7%		5%	
	Fans	41%	7%		4%	
	Conveyors	39%	8%		5%	2%
	Cooling towers	29%	7%	2%	2%	
	Process control devices	40%	18%	3%	18%	4%
	Grinders	39%	3%		6%	
	Crystallizers	43%	16%	11%	14%	
	Devices for process analysis	43%	14%	10%	15%	11%
	Instruments	38%	18%	3%	8%	11%
	Distillation towers	53%	22%	2%	2%	
	Absorbtion towers	58%	16%	2%	3%	
	Dryers	56%	8%	1%	4%	
	Evaporators	51%	10%		7%	
	Fired heaters	31%	6%		12%	
	Gaskets and Sealings	53%	3%	4%	6%	1%
	Gas purification units	45%	15%	4%	2%	6%
	Heat exchangers	57%	18%	8%	4%	
	Mechanical separators	48%	8%		5%	2%

PFAS presence in equipment		Seals (Gasket, O-ring)	Coating	Piping	Valves	Membranes
Process unit's equipment	Motors and couplings	39%	6%		4%	
	Reactors	55%	23%	12%	10%	5%
	Refrigeration systems	36%	3%	1%	4%	1%
	Piping	36%	37%	31%	7%	
	Pumps	59%	25%	1%	8%	13%
	Steam ejectors	31%	10%		2%	2%
	Vacuum pumps	55%	13%	1%	7%	5%
	Valves and Accessories	51%	23%	1%	34%	4%
	Vessels	42%	39%	4%	9%	
	Wastewater treatment	40%	12%	11%	11%	4%
Safety & protection	PPE	1%	4%			
	Plant Safety Equipment	8%	1%	2%	13%	
Power & utilities	Power Supply Equipment	8%	1%		2%	
	Plants Cable & Wiring Equipment	1%				
Other products	Greases	5%		1%		
	Lubricants	4%				
	Plants Catalysts					3%
	Refrigerants					
	Processing aids		4%	2%		4%

Example of components in PPE and Plant safety equipment

Plant safety equipment
- Firefighting foam
- Safety valves

PPE
- Gloves
- Face masks
- Work clothings (plant)
- Fire protection
- Lab coats

Source: Accenture analysis of questionnaires

In which equipment are PFAS present?

Article analysis through advanced analysis confirmed the survey results - below is a sample of the results

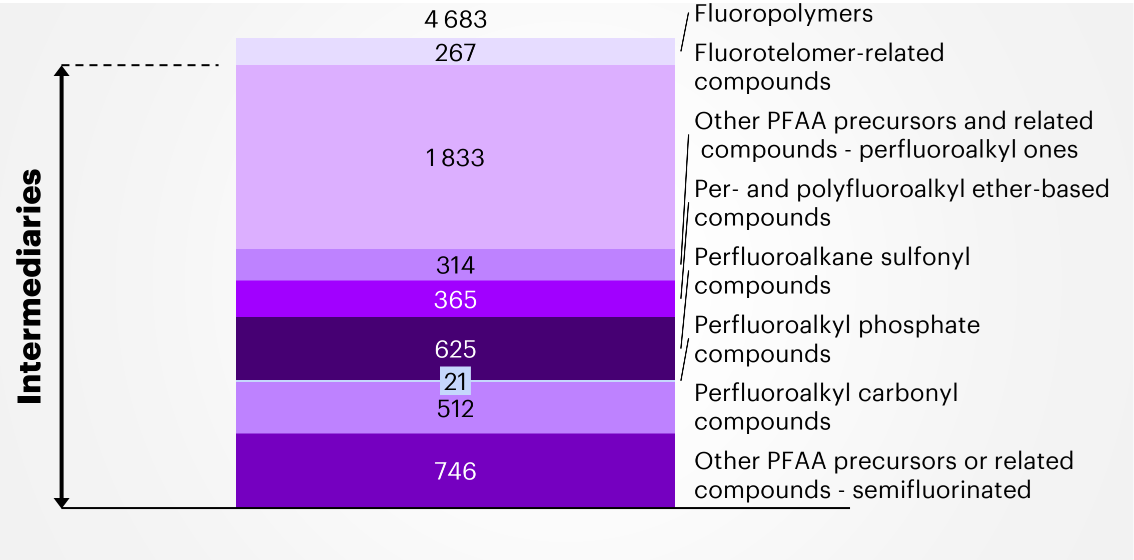
Chemical Equipment	PFAS Name	Use
Seals & O-Rings	FFKM	FFKM provides exceptional **high temperature and high-pressure performance** to equipment parts like O-Rings and seals. FFKM can also be used to **increase the mean time between failure** (MTBF) of a screw spindle pump in a petrochemical plant
Membranes	PTFE	PTFE is used in TPV membrane modules. PTFE is used as a backbone to **suppress the swelling of Nafion** component in composite membranes for high temperature PEM fuel cell applications
Membranes	PVDF	PVDF is used to **produce ultrafine hollow fiber membranes** for lactic acid extraction
Cooling Towers	PVDF	PVDF is used to **reduce microbiological activity** in cooling tower systems. It helps with **sunlight resistance** and is used in the construction of sodium hypochlorite feed systems to inhibit the growth of algae and bacterial species in cooling towers
Heat Exchangers	PTFE, FEP, PVDF	PTFE, FEP, and PVDF materials can be included in the **oleophilic surface** of a heat exchanger
Piping	PTFE	PTFE is used to **form hydrophobic pigs** in a method of minimizing the mixing of aqueous-based materials in pipes
Coating	PTFE	PTFE coating is used for **antifouling purposes** in gas-absorption desulfurization
Batteries	PVDF	PVDF is an **indispensable binder** for lithium battery cathode materials
Pumps	ETFE	ETFE is used for a **wide range of corrosives and solvents**
Diaphragm Pumps	PTFE	PTFE is used in metering diaphragm pumps because of its **chemical resistance**
UV reactors	PTFE	PTFE is used in UV reactors as a diffusive surface **to increase the UV radiation** intensity with water
Refrigerant gas	R410	R410 offers **high thermal conductivity** and **high stability**
Valves	PTFE	A PTFE stem sealing system (V-Pack) is mentioned as a new advanced sealing system for valve stems that removes the need for an elastomer O-ring, making the valve suitable for use with a **wide range of chemicals**

Source: Accenture text mining analysis

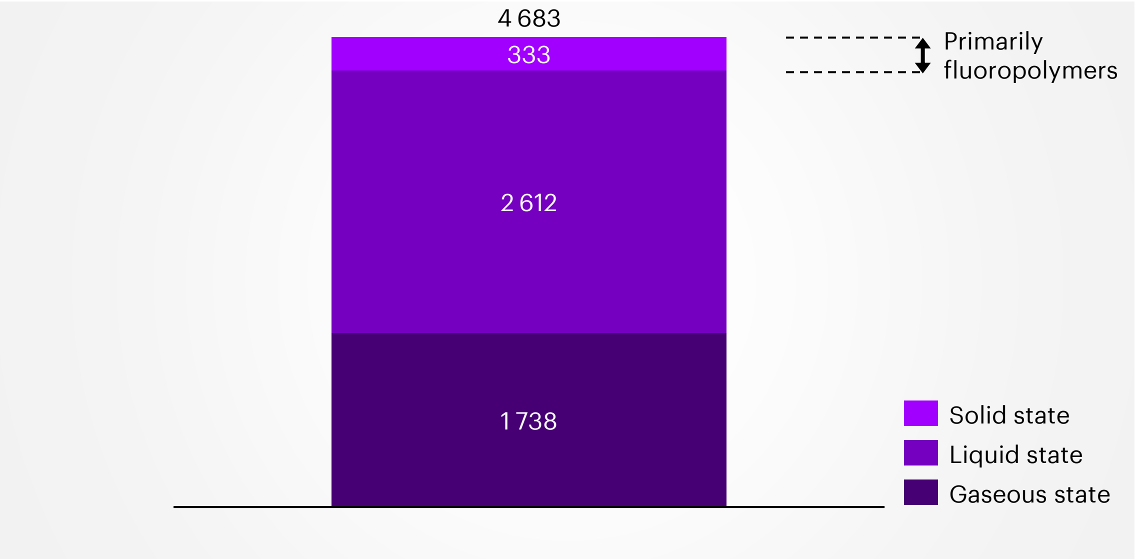
Which PFAS are present?

Predominantly used as a raw material in chemical synthesis, PFAS are mainly found in solid form in industrial equipment, primarily as fluoropolymers

PFAS distribution by main category



PFAS distribution by state



- **More than 90%** of the PFAS are used in gaseous or liquid state — in terms of substance classification
- **Solid PFAS,** mainly fluoropolymers, represent a small portion of the total substances (~5%) — in terms of substance classification

Source: Analysis based on OECD Database, under the following hypotheses: Chain length <5 = Gaseous state ; >20 = Solid state ; 5< & <20 = Liquid state

Which PFAS are present?

3 groups of PFAS used in industrial equipment were identified, representing ~50 types of PFAS

Identified PFAS substances*

Solid State

Fluoropolymers	**PFAS compounds**
FKM *(Viton, Tecnoflon, Dyneon,…)*	PFSA**
FFKM *(Kalrez, Tecnoflon,…)*	PFCA**
PTFE *(Teflon, Gylon)*	
FEP	
PFA	
PVDF *(Kynar, Hylar, Solef)*	
ETFE	
PCTFE	
ECTFE	

Liquid State

Lubricants/Greases	**Firefighting foams**
PFAE	C6 Foams *(SFPM***)*
PFPE	PFBA
PFPAE	PFOA
PTFE *(Interflon, Oraflon, Nevastane HD2T)*	PFOS
PCTFE *(Voltalef)*	PFNA
	PFBS
	FK-5-1-12

Gaseous State

HCFC	**HFC**
HCFC-123	HFC-134a
	HFC-143a
	HFC-365mfc
HFC/HFO - Blends	**HFO**
R-448A	HFO-1233zd
R-449A	HFO-1234yf
R-452A	HFO-1336mzz
R-513A	
HFC - Blends	
R-401A	R-417A
R-404A	R-422D
R-407	R-427A
R-410A	R-507

**PFAS list is potentially not exhaustive, the brand names identified are presented in (italic), **PFSA and PFCA are not fluoropolymers, ***Film-forming alcohol-resistant fluor synthetic emulsifier*
Source: Accenture analysis of questionnaires, Text mining, Interviews of chemical companies and suppliers

Which PFAS are present?

Fluoropolymers are the main PFAS types in chemical process unit's equipment (1/2)

PFAS presence in Process Unit's Equipment

Process Unit's Equipment

PFAS Category*	Agitators	Com-pressors	Turbines	Fans	Conveyors	Cooling towers	Crushers	Grinders	Crystallizer	Process control	Wastewater Treatment	Process analysis	Instrume-nts	Absorption towers	Distillation towers
Perfluoroalkyl acids	1	1		2	2	2	1	2		2		2	2	2	1
Perfluoroalkane sulfonyl fluorides				1	1										
Perfluoroalkane sulfonamides															
Perfluoroalkyl iodides															
Perfluoroalkyl aldehydes												1			
F-Gases (HFCs, HFOs, …)		5	1	1		2				1			1		
Fluoropolymers**	57	48	20	34	32	21	20	17	21	46	28	47	53	36	43
Side-chain fluorinated polymers	3	3	1	1	2					2		1	2	1	4
Perfluoropolyethers	5	3	1	4	5	1	1	3	3	3	1	2	3	2	3
Polyfluoroalkane sulfonamido															
Fluorotelomer-based compounds	3	2	2	2	3	1	1	1	1	1	1	1	1	1	2
Poly-fluorinated n-alkanes & alkenes	2	2	1	2	1	1	1			2	1	2	4	1	2
Others	16	15	6	9	7	6	6	5	2	19	10	20	22	11	9

**Frequency for which a specific category of PFAS is mentioned for a specific equipment **Including fluoroelastomers*
Disclaimers : Representative of European chemical landscape, 100+ companies and 1000+ plants
Source: Accenture analysis of questionnaires

Which PFAS are present?

Fluoropolymers are the main PFAS types in chemical process unit’s equipment (2/2)

PFAS presence in Process Unit’s Equipment

	Process Unit’s Equipment															
PFAS Category*	Dryers	Fired Heaters	Gaskets Sealings	Evapo-rators	Gas purify. units	Heat Exchanger	Mec. separators	Motors & Couplings	Reactors	Vessels	Piping	Pumps	Steam Ejectors	Vacuum pumps	Valves	Other Proc. equip.
Perfluoroalkyl acids	1	1	2		1	1	1	2	2	2	3	2		2	2	3
Perfluoroalkane sulfonyl fluorides											1	1			1	2
Perfluoroalkane sulfonamides			1													
Perfluoroalkyl iodides	1															
Perfluoroalkyl aldehydes				1												
F-Gases (HFCs, HFOs, ...)	1			1	2	2										1
Fluoropolymers**	35	19	72	32	25	56	35	36	47	46	66	72	16	48	68	33
Side-chain fluorinated polymers	1		6	1		3	1	5	2	1	3	4		3	2	1
Perfluoropolyethers	4	3	5	1	2	3	3	4	5	3	5	5		5	4	3
Polyfluoroalkane sulfonamido																
Fluorotelomer-based compounds	1	1	3	2	1	2	1	3	2	1	2	3	1	3	1	1
Poly-fluorinated n-alkanes & alkenes	3	2	2	2	1	3	1	1	2	3	1	3		1	2	1
Others	13	7	33	9	9	21	10	12	16	23	30	28	5	13	30	9

**Frequency for which a specific category of PFAS is mentioned for a specific equipment ** Including fluoroelastomers*
Disclaimers : Representative of European chemical landscape, 100+ companies and 1000+ plants
Source: Accenture analysis of questionnaire

Which PFAS are present?

PFAS are also found in several other categories of equipment

PFAS presence in other equipment

	Safety and Protection		Power & Utilities		Other Products					
PFAS Category*	PPE	Plant Safety	Power supply Equip.	Plant Cables & Wiring Equip.	Greases	Lubricants	Catalysts	Refrigerants	Processing aids	Others
Perfluoroalkyl acids	1	7	1	1	1	1	1			2
Perfluoroalkane sulfonyl fluorides	1		1							2
Perfluoroalkane sulfonamides				1					1	
Perfluoroalkyl iodides		1								
Perfluoroalkyl aldehydes										
F-Gases (HFCs, HFOs, ...)		5	6					49		1
Fluoropolymers**	30	14	19	23	18	19	1	2	11	15
Side-chain fluorinated polymers	1	1		1						1
Perfluoropolyethers	1	2	1	1	3	5				1
Polyfluoroalkane sulfonamido		1								
Fluorotelomer-based compounds	2	3	1	1						
Poly-fluorinated n-alkanes & alkenes	3	3		3	2	1		2	1	1
Others	10	16	10	7	10	11	3	10	2	4

**Frequency for which a specific category of PFAS is mentioned for a specific equipment **Including fluorelastomers*
Disclaimers : Representative of European chemical landscape, 100+ companies and 1000+ plants
Source: Accenture analysis of questionnaires

Which PFAS are present?

Product data analysis through advanced analytics confirmed these findings

Data collection*

- Equipment data was collected on the categories listed below:

Category, subcategory	Count of equip. classes	PFAS type
Detection - Measurement	**33**	
Flow, pressure and level measurement	20	PFA, PTFE, VDF, FFKM, FM200, PFC, ETFE, R134 a, ECTFE, R407 c, R1234 yf, FEP, FKM
Temperature and humidity measurement	13	FKM, PTFE, FFKM, PFC, FEP, PFA, PVDF, ETFE, FTO
Environment - Health - Safety	**38**	
Air treatment and noise management	21	ECTFE, ETFE, FFKM, FKM, FTI, PFA, PFC, PTFE, PVDF, PVF, SFA
Personal protective equipment	6	PTFE, FFKM, PFC
Waste treatment	2	FTO, PTFE
Water treatment	9	ECTFE, FFKM, FTI, PFA, PFC, PTFE, PVDF, SFA, VDF
Hydraulics - Pneumatics	**98**	
Compressors	11	R134 a, PTFE, FFKM, FKM, R407 c
Filters and separators	21	ECTFE, ETFE, FEP, FFKM, FKM, PFA, PTFE, PVDF, SFA, VDF
Hydraulic and pneumatic actuators	2	FKM, PTFE, PVDF, PTFE, FFKM
Pipes, tubes and fittings	22	R134 a, R407 c, PTFE, FEP, PFA, PVDF, FFKM, ETFE, PVF, ECTFE, FKM, PFC
Pumps	16	ECTFE, ETFE, FEP, FFKM, FKM, FTI, PFA, PTFE, PVDF, SFA, VDF
Valves	26	ECTFE, ETFE, FEP, FFKM, FKM, PFA, PFC, PTFE, PVDF, PVF, VDF
Industrial machines and equipment	**49**	
Furnaces and heat treatment	9	PVDF, PFA, PTFE, R134 a, R407a, FFKM
Heat exchangers and refrigeration	20	PTFE, FEP, PVDF, PFA, FFKM, ECTFE, R134 a, R407 a, c, R1234 yf, R452 a
Mixing and dosing	20	ECTFE, ETFE, FEP, FFKM, FKM, FTO, PFA, PFC, PTFE, PVDF

Source: Accenture text mining, Equipment data collected from directindustry.com

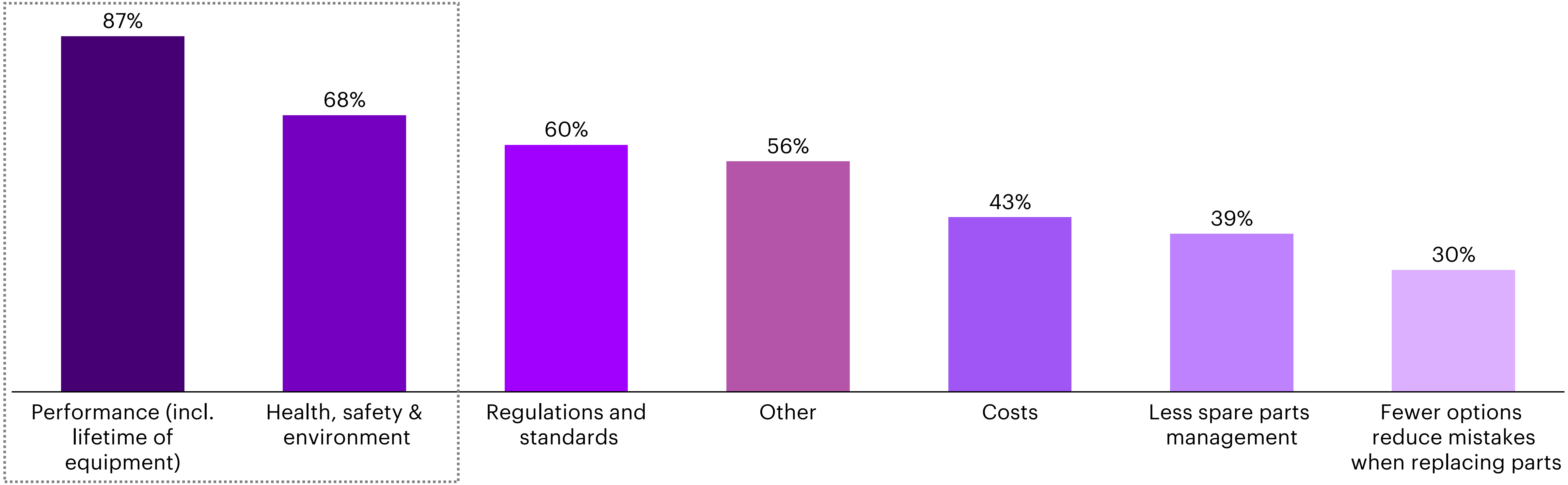
Analysis

- In total there were **62 427 equipment products identified**, with material information
- Out of those 62k+ products, 11 235 are tagged as chemical equipment
- Out of those, 62k+ products, 2 571 mentioned PFAS names
- Out of those 62k+ products, **345 classes of equipment have been analyzed**

Category, subcategory	Count of equip. classes	PFAS type
Materials – Tools - Components	**25**	
Lubricants	10	FFKM, FKM, PTFE, PFPE, PVDF, VDF
Semi-finished products	15	ETFE, FEP, FFKM, FKM, PFA, PTFE, PVDF, R1234 yf, R134 a
Packing – Health - Logistics	**49**	
Conveying	13	FKM, PTFE, FDF
Handling and lifting	11	PTFE, FFKM, PFC
Packing and Packaging	17	PTFE, FKM, FFKM, PVDF, PCTFE, FEP,
Storage	8	PTFE, FKM, ECTFE, FFKM, FEP, ETFE, PFA, PVDF,
Power Transmission – Mechanical Components	**43**	
Actuators and positionning systems	9	PTFE, FFKM, PVDF, R134 a, R407 c
Bearing and linear guides	8	PTFE, FFKM, SFA, FKM
Mechanical Transmission	23	FFKM, PTFE, PFA, PVDF, PVC
Motors and Motor Control	3	R134 a, R407 c, PTFE, FEP, PFA, PVDF, FFKM, ETFE, PVF, FKM, PTFE, FEP
Production Machines	**10**	
Forming machines	10	PTFE, PFC
Total Number of Equip. Classes	**345**	

Why are PFAS used?

Ensuring performance and health and safety are the main reasons for using equipment containing PFAS



Influential factors in companies' preference for PFAS equipment (% of companies)*

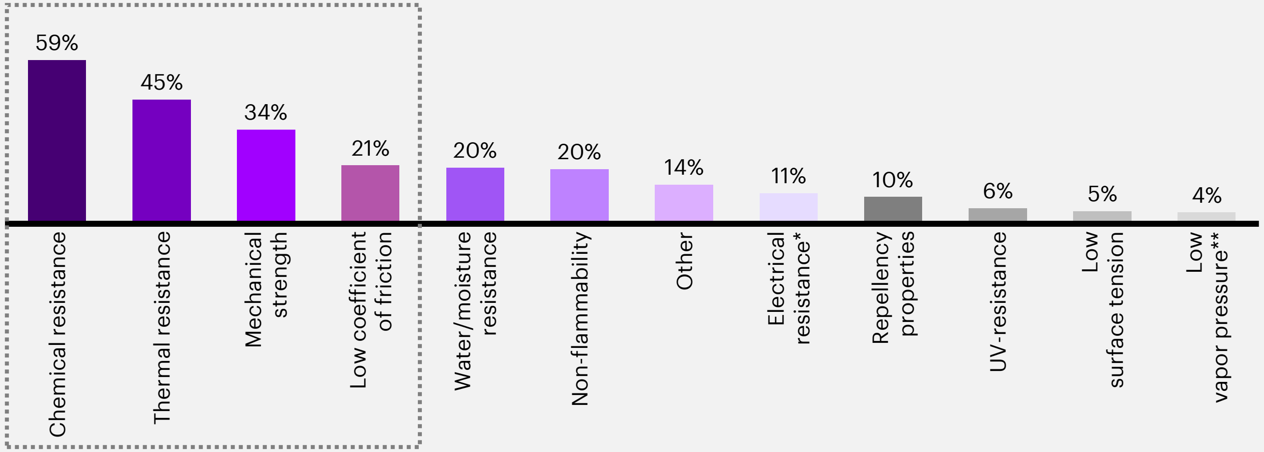
**The provided percentage for factor X was calculated by counting the number of companies that indicated "yes" to the X factor among the given options for their equipment (companies could select more than one option). Then, this count was divided by the total number of companies that responded to the question. This provided the percentage of companies that are influenced by the factor X in their preference for PFAS equipment.*
Source: Accenture analysis of questionnaire

Why are PFAS used?

Fluoropolymers are the main category of PFAS found in chemical plant equipment because they display a unique set of combined properties

Distribution of the sought-after properties in PFAS according to the companies

Chemical resistance, thermal resistance and mechanical properties (mechanical strength & low friction coefficient) are the **most sought-after attributes** in PFAS



Proportion of companies seeking specific properties in PFAS (% of Companies)***

Top three sought-after properties in PFAS

Chemical resistance

- **High resistance to corrosion:** Resistance to aggressive products (pH<1) such as nitric acid and chloride acid
- **Chemical inertia:** Material that degrades little over time, little product contamination (i.e., no impurities)

Thermal resistance

- **Wide operating temperature range:** For example, PTFE has a permissible temperature range of [-20–260] °C and can withstand high temperatures without degradation

Mechanical properties

- **High mechanical strength:** Can withstand mechanical stress and deformation
- **Low friction coefficient:** Non-stick and lubricants properties

**Corresponds to the dielectric constant **For Vacuum applications ***The provided average percentage was obtained by computing the ratio of the number of companies expressing interest in property X for equipment Y to the number of companies reporting PFAS-containing equipment Y, across all equipment types.*
Sources: Interviews of chemical companies, Questionnaire, Desktop research, Accenture analysis

Why are PFAS used?

PFAS in sealings, pipes and valves in chemical plants are chosen for one or more of these properties (1/3) – Focus on gaskets/sealings

Type of gaskets/sealings	**Static gaskets/sealings**	**Dynamic gaskets/sealings**
Common functions	Static sealing: Sealing between two parts with no (or very low) relative movement	Dynamic sealing: Sealing between two parts with relative rotational and, or translational movement
Types of PFAS present	e.g., PTFE, PVDF, PFA, FFKM, FKM, PCTFE, FEP, ECTFE	
Desired properties	• Mechanical resistance: tensile strength and limited swelling • Chemical resistance: resistant to chemical attacks	• Mechanical resistance: high pressure (0 to 750 bar), low fatigue, high tensile strength • Thermal resistance: very low and high temperatures (-50 to +300 °C) • Used when the application goes beyond the limits of traditional lip seals

Sources: Eriks, Interviews of chemical companies and suppliers

Why are PFAS used?

PFAS in sealings, pipes and valves in chemical plants are chosen for one or more of these properties (2/3) – Focus on piping

Type of piping	Internal coating	Solid piping
Common functions	Transport of highly acid or basic fluids under extreme temperatures	Transport of highly acid or basic fluids
Types of PFAS present	e.g., PTFE, PVDF, PFA, FFKM, FKM, PCTFE, ECTFE	
Desired properties	• Chemical resistance: corrosion resistance • Thermal resistance: operating temperatures from -50°C to +260°C	• Chemical resistance: highly resistant to chemicals, rot-proof and mildew-proof • Thermal resistance: operating temperatures from -50°C to +150°C • Other properties: insensitive to ultraviolet rays, highly waterproof, non-flammable (UL V0)*

*UL V0 is used to classify the flammability of plastics base on their ignition and combustion characteristics.
Sources: Mersen, Tecalemit, Interviews of chemical companies and suppliers

Why are PFAS used?

PFAS in sealings, pipes and valves in chemical plants are chosen for one or more of these properties (3/3) – Focus on valves

Type of valves	Valves with some PFAS components	PFAS-only valves
Common functions	Control flow of highly acid or basic fluids under extreme temperatures	Control flow of highly acid or basic fluids under extreme temperatures and high purity standards
Types of PFAS present	e.g., PTFE (sleeve)	e.g., PVDF (body), FPM (gaskets), PTFE (membrane)
Desired properties	• Chemical resistance: chemical resistant lining • Thermal resistance: -20°C < T < 210°C • Mechanical resistance: vacuum-proof lining	• Chemical resistance: resistant to acid and basic liquids • Thermal resistance: -30°C < T < 120°C

Sources: Az-Armaturen, Sectoriel, Interviews of chemical companies and suppliers

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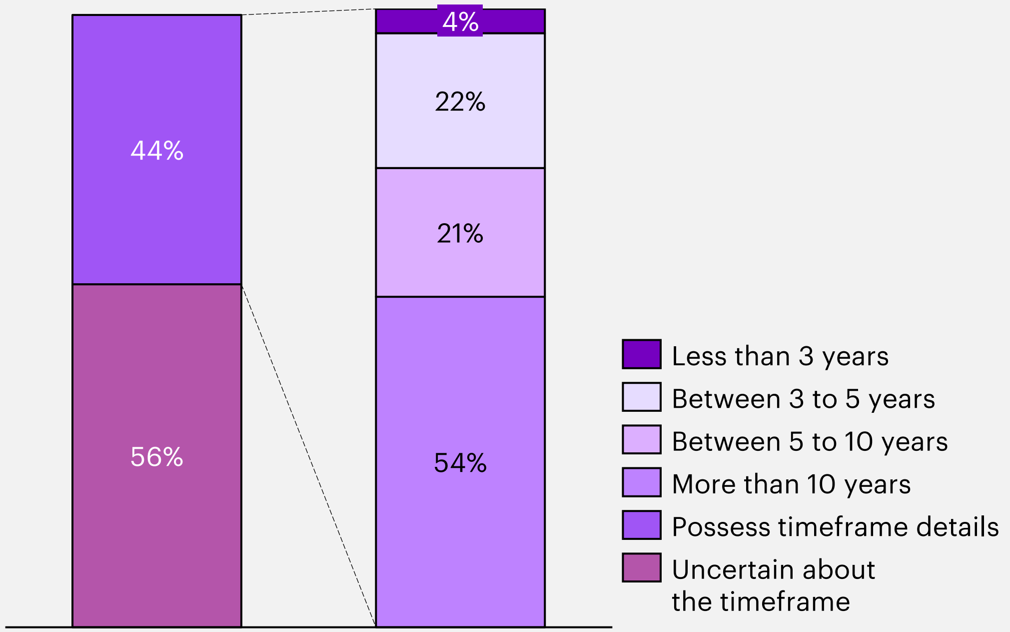
The challenge of substitution

A timeframe of +10 years will be needed to substitute PFAS in equipment when alternatives are identified, according to companies

Timeframe for PFAS replacement



Estimated time needed for equipment replacement (% of equipment) when companies provided a timeframe*

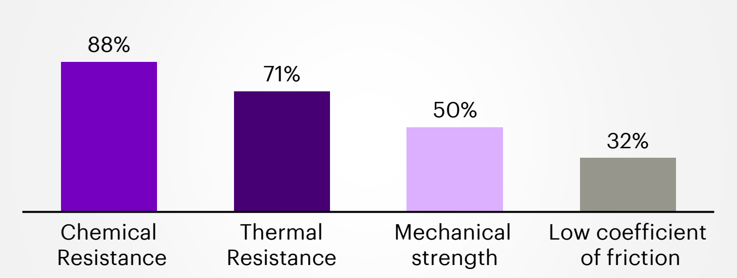
- **56%** of companies are **uncertain about the time that would be required to replace PFAS** with alternatives
- When companies provided a timeframe for **PFAS replacement**, they estimate that it would take **more than 10 years for 54%** of their **equipment**

**The provided percentage for a substitution strategy per equipment X was calculated by taking the number of "yes" for an equipment X divided by the total of answer for the substitution strategy.*
Source: Accenture analysis of questionnaires

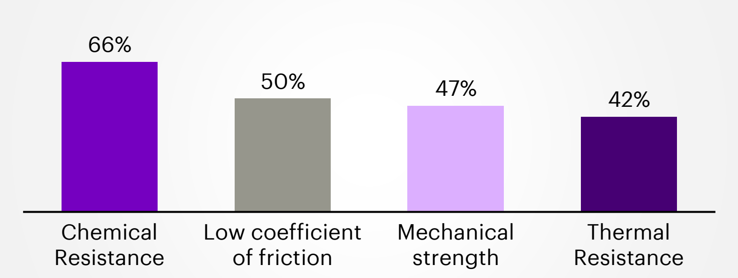
The challenge of substitution

The complexity of replacing PFAS in equipment is heightened by the varying combinations of properties sought for each application

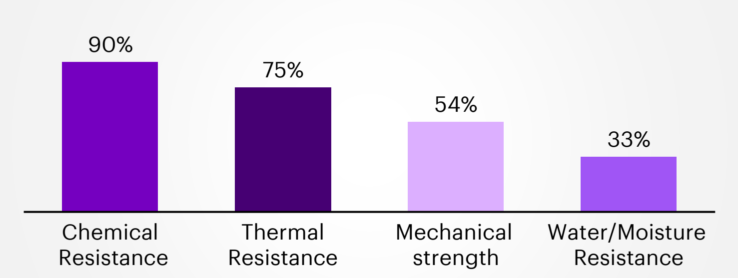
Pumps



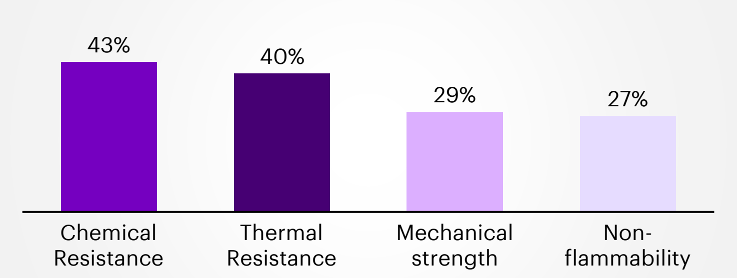
Conveyors



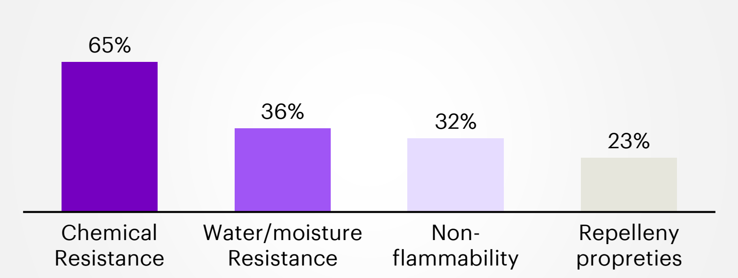
Gaskets & Sealings



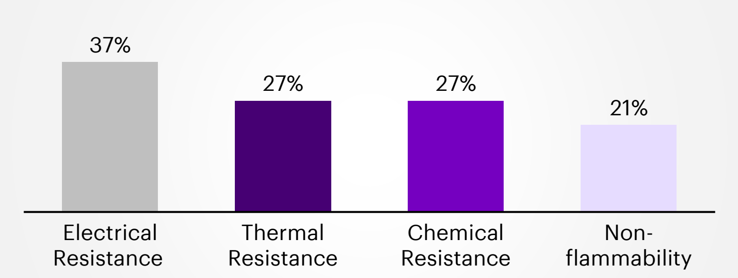
Refrigeration systems



PPE



Power Supply Equip.



Top four sought-after properties for six PFAS-containing equipment (% of Companies)*

**The provided percentages indicate the number of companies that expressed interest in property X for equipment Y, divided by the number of companies that reported having the respective PFAS-containing equipment Y.*
Source: Accenture analysis of questionnaires, List of illustrations is in the appendix

The challenge of substitution

For some equipment, alternatives are not available or viable to date

Equipment	Illustration	PFAS	Alternatives' limits
Membranes & diaphragms for Electrolysis		PFSA, PTFE (Nafion, Aquivion)	• Some alternatives are banned in Europe (mercury technology, asbestos diaphragms) • There is no technical solution to date that can efficiently perform the filtration, the separation and the selectivity

Sources: Denora, Interviews of chemical companies and suppliers, Desktop research, Accenture analysis

The challenge of substitution

Equipment	PFAS	Alternative	Alternatives' limits
Gaskets	PCTFE, PTFE	Metallic (e.g., Nickel) gaskets	Not suitable for excessive torque tightening
	PTFE	Graphite or Mica (silicate) gaskets	Possible contamination issues
		EPDM, NBR**	Lower Chemical resistance (less safety in chemical plants, higher emissions)
		Organic, mineral fibre gaskets	Sealing level reduced by x(100-1000), shorter life span
Piping	PTFE, PFA, PVDF	TPM (Thermoplastics materials) (HD-PE, PP, U-PVC, C-PVC), SVR	Lower upper temperature limit and lower chemical resistance
		FRP (Fiber Reinforced Plastic)	Lower upper temperature limit and lower chemical resistance
		Hastelloy	Material heavy weight can induce changes in structural design changes of supports and civil construction
		Glass lining	Mechanical fragility
		Enamelled Steel, Nickel, Titanium	Mounting constraints, lower resistance to chemical reaction

**The list of PFAS and alternatives identified is not exhaustive. **EPDM and NBR have insufficient chemical resistance for chlorine, sulfuric acid and nitric acid. In addition, NBR has insufficient chemical resistance for ammonia*
Sources: Unique Polymers; sgl carbon; Debrunner Acier, Interviews of chemical companies and suppliers, Desktop research, Accenture analysis

The challenge of substitution

Equipment	PFAS	Alternative	Alternatives' limits
Valves Bodies (large components)	PCTFE	Vespel	No specific limits identified except high cost
	PTFE	Enamelled steel valves, Hastelloy Noble metal grade	Higher friction coefficient and lower sealing capacities, low availability
Valves – Washers* (Intermediate components)	PTFE	Polyethylene	Lower upper temperature limit
Valves - Gaskets	FKM, PTFE	EPDM	Lower chemical resistance, not suitable for all applications
Refrigerant	Refrigerant	Ammonia	Higher risks due to toxicity, impact on refrigerant auxiliary system design and on energy consumption
		CO2	Much higher-pressure requirements for cooling, impact on refrigerant auxiliary system design and on energy consumption, narrower applicable temperature range, mainly applied in commercial refrigeration
		Hydrocarbons (e.g., Propane, Isobutane, Butane)	Highly flammable gas, impact on refrigerant auxiliary system design and on energy consumption, high GHG impact, mainly applied in commercial refrigeration, temperature of use must not be too high**
Coating	PTFE, PVDF	PPV, Epoxy, Polyester, Melamine	Lower UV durability, corrosion resistance (e.g., for seaside applications) and resistance regarding high temperatures

**The list of PFAS and alternatives identified is not exhaustive **Parts ensuring friction and sliding ***The temperature difference between the desired cooling temperature and the outside temperature should not be too great, this is due to the specific properties of propane as a refrigerant.*
Sources: Ferguson industrial, Alundong, BuyBestAc, Interviews of chemical companies and suppliers, Desktop research, Accenture analysis

The challenge of substitution

Some examples of potential alternative materials for specific uses (1/3) – Focus on identified PFAS alternatives by categories

Materials in Chemical Equipment

Solid State

Polymers

Plastics
- PVC
- PEEK
- PPS
- PSU

Elastomers
- NBR
- EPDM

Metals

- Stainless Steel
- Nickel Alloys
- Hastelloy
- Exotic material (Tantalum, Zirconium, Titanium)

Other Materials

- Glass
- Ceramics
- Graphite

Liquid State

Lubricants, Greases

- Powder Graphite
- Molybdenum

Foams

- Hydrocarbons
- Detergents
- Siloxanes
- Proteins

Gaseous State

Refrigerant

- Ammonia
- CO_2
- Hydrocarbons (e.g., Propane, Isobutane, Butane)

For some applications, such as **electrolysis membranes**, there are **no substitutes identified** to this date

Sources: Questionnaires, Interviews of chemical companies and suppliers, Desktop research, Accenture analysis

The challenge of substitution

Some examples of potential alternative materials for specific uses (2/3) – Focus on Thermoplastics (other polymers)

Thermal Resistance			
	Symbol	**Material name**	**Max. working T. [°C]**
Fluoropolymer	PTFE	Polytetrafluoroe-thylene	260
	PFA	Perfluoroalkoxy polymer	150
	PVDF	Polyvinylidene fluoride	150
Alternatives	PEEK	Polyetherketone	250
	PPS	Polyphenylene sulfide	240
	PSU	Polysulfone	150
	PEI	Polyetherimide	170

Table 1: List of selected heat-resistant plastics[1]

In terms of **working temperatures** alone, some **alternative plastics** can be found for certain PFAS

(ASTM 2000, SAEJ20)

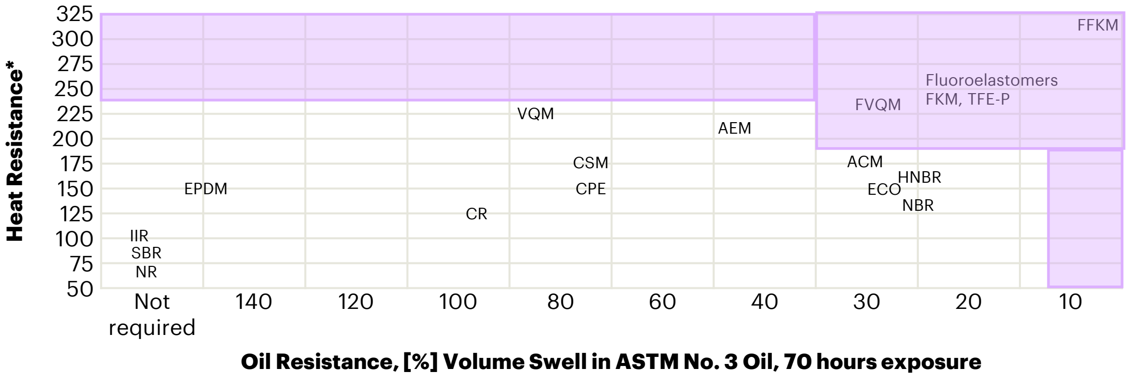


Figure 1: Elastomer family's plastics rated against heat and oil resistance[3]

The ASTM swelling test for elastomers shows that **in the domain of high temperature** (>200°C), **fluoroelastomers** are the most suitable materials

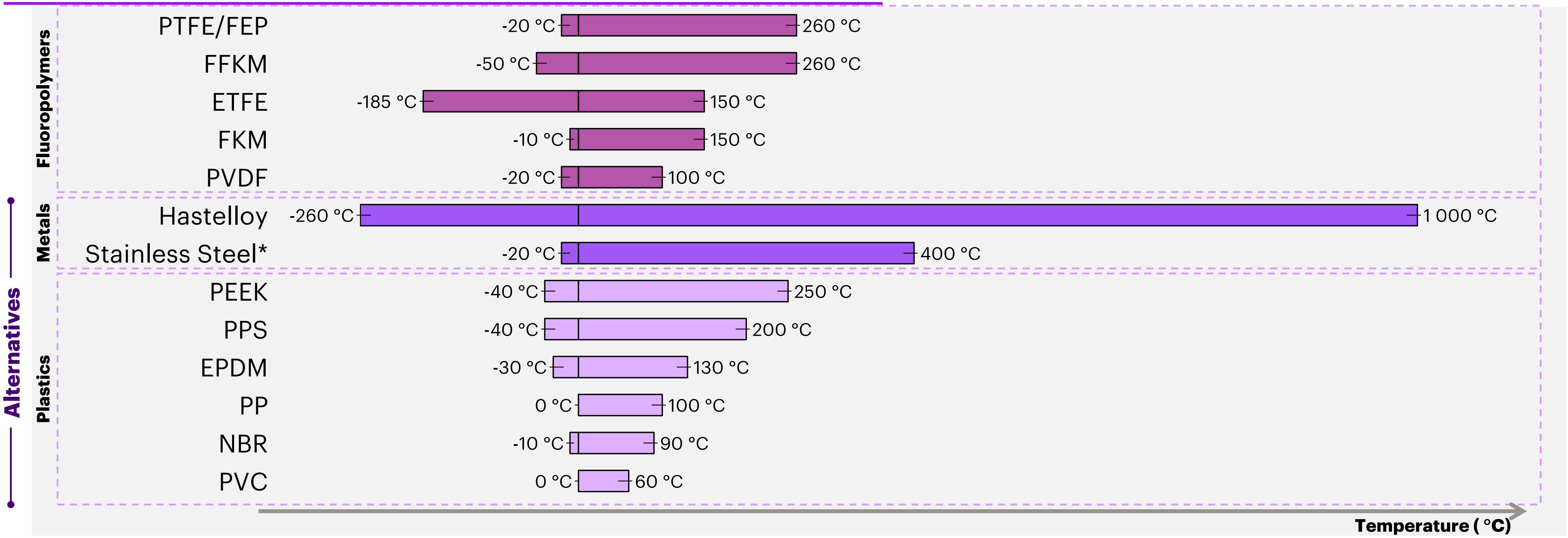
*Maximum time at which vulcanizates can be aged for 70 hours with changes in tensile strength ≤ ±30%, elongation ≤-50% and hardness ≤ ±15points

Sources: [1] Design and Manufacturing of Micro-Turbomachinery Components with Application of Heat Resistant Plastics, June 2018. [2] https:, , www.glsciences.com, technique, technique_data, lc, usage_of_hplc_1, column12.html. [3] Choosing the right elastomer for the right application Stahl W, World Pumps, 2006, 481, 2006 Oct, pp 30-33

The challenge of substitution

Some examples of potential alternative materials for specific uses (3/3) – Certain materials can withstand high temperatures like PFAS substances

Permissible temperature of materials



*Stainless Steel 3 16Ti

Sources:. https://burkert.poznan.pl/pdf/tochen.pdf, https://www.haynesintl.com/alloys/alloy-portfol..., https://www.polyfluor.nl/en/materials/peek/ , https://burkert.poznan.pl/pdf/tochen.pdf

The challenge of substitution

However, these potential alternatives often do not match all the required properties of PFAS substances (1/2) - When temperature is combined with chemical resistance, potential alternatives are less performant than PFAS

Overview of the chemical resistance of materials at 20°C and 60°C[1,2]

			Fluoropolymers					Metals (Alternatives)		Plastics (Alternatives)					
Category of substances	**Substances**	**Temp. [°C]**	**PTFE/FEP**	**PVDF**	**ETFE**	**FFKM**	**FKM**	**Stainless Steel***	**Hastelloy**	**PP**	**PPS**	**PVC**	**NBR**	**PEEK**	**EPDM**
Strong acids	Sulphuric Acid (conc. 98%)	20	+	+	+	+	+	+	+	0	0	0	-	-	0
		60	+	+	+	+	-	0	+	0	-		-	-	0
	Hydrochloric Acid (conc. 30%)	20	+	+	+	+	+	-	+	+	+	+	-	0	+
		60	+	+	+	+	0	-	0	+	+		-		0
	Nitric Acid (conc. 65%)	20	+	+	+	+	0	+	+	-	-	+	-	0	-
		60	+	+	+	+	0	0	0	-	-	0	-	0	-
Strong Bases	Sodium Hydroxide (NaOH) (conc. 50%)	20	+	0	+	+	0	+	+	+	+	+	0	+	+
		60	+	0	+	+	-	0	+	+	+		-	+	+
	Potassium Hydroxide (KOH) (conc. 60%)	20	+	+	+	+	-	+	+	+	+	+	-	+	+
		60	+	+	+	+	-	+	+	+	+	+	-	+	+
Oxidizing Agents	Potassium permanganate (KMnO4) (conc. 6%)	20	+	+	+	+	+	+	+	+	+	+	0	+	+
		60	+	+	+	+	+	+	+	+	+	0	0	+	+
	Hydrogen peroxide (conc. 20%)	20	+	+	+	+	+	+	+	+	0	+	0	+	+
		60	+	+	+	+	0	+	+	+	0		-	+	-
Halogen Compounds	Sodium fluoride (conc. 4%)	20	+	+	+	+	+	+	+	+	+	+	+	+	+
		60	+	+	+	+	+	0	+	+	+	+	0	+	+
	Sodium chlorite (conc. 5%)	20	+	+	+	+	+	0	+	+	+	-	+		+
		60	+	+	+	+	+	-	0	+	+		0		+
	Bromine (technically pure)	20	+	+	+	+	0	-	+	-	-	+	-	-	-
Aromatic Hydrocarbons	Benzene	20	+	+	+	+	+	+	+	-	+	0	-	+	-
	Toluene	20	+	+	+	+	0	+	+	0	+	-	-	+	0
		60	+	+	+	+	0	+	+	0	+		-	+	-
Esters	Acetic Methyl Ester (conc.100%)	20	+	+	+	+	-	+	+	+	+		-		-
		60	+	-	+	+	-	+	+	+	+		-		-
Ketone	Dissobutyl Ketone (conc. TR)	20	+	+	+	+	+	+	+	+	+	-	-		+
		60	+	+	+	+	-	+	+	+	+		-		+
Aldehydes	Propylene Aldehydes/Butenal/Crotonaldehyde	20	+	+	+	+	+	+	+	-	+	-	+		+
Aliphatic alcohols	Methanol (conc. TR)	20	+	+	+	+	0	+	+	+	+	+	0	+	+
		60	+	+	+	+	0	+	+	+	+	0	-		0
	Ethanol (conc. TR)	20	+	+	+	+	+	+	+	+	+		+	+	+
		60	+	+	+	+	0	+	+	+	+		+		+

Legend
- + Compatible
- 0 Limited compatibility
- - Not compatible
- (blank) Information not provided

**Stainless Steel 316Ti*

Sources:.[1] https://fluids.fr/_iserv/dlfiles/dl.php?ddl=compatibilite-materiaux-flux.pdf, [2] chemline_chemical_resistance_guide_2015.pdf (everythinginsidethefence.com), https://www.theplasticshop.co.uk/plastic_technical_data_sheets/engineering_plastics_chemical_resistance_guide.pdf, https://burkert.poznan.pl/pdf/tochen.pdf

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The challenge of substitution

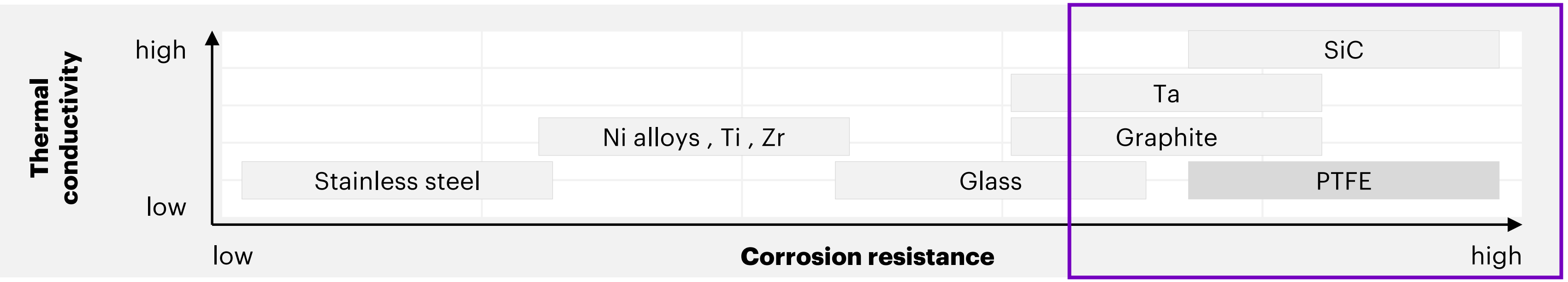
However, these potential alternatives often do not match all the required properties of PFAS substances (2/2) - Focus on Metals & Glass

Comparing the properties of metals and glass with fluoropolymers

When compared to fluoropolymers, metals and glass offer lower levels of resistance in terms of chemical resistance and formability

Potential alternatives to fluoropolymers	Thermal resistance	Mechanical resistance	Chemical resistance	Formability
Metals (eg. Rare Metals, Alloys, SST)	Equivalent or better	Equivalent or better	Worse or equivalent (eg. Ta)	Worse or equivalent (shape creation)
Glass	Equivalent	Worse	Worse	Worse

Metals and glass rated against corrosion resistance and thermal conductivity*



- Graphite, SiC (Silicium Carbide) and Tantalum can offer alternatives to PTFE in terms of chemical resistance
- The brittleness of SiC makes it not ideal for equipment as reactors, agitators or columns

*Source: *SGL carbon, Desktop research, Accenture analysis*

The challenge of substitution

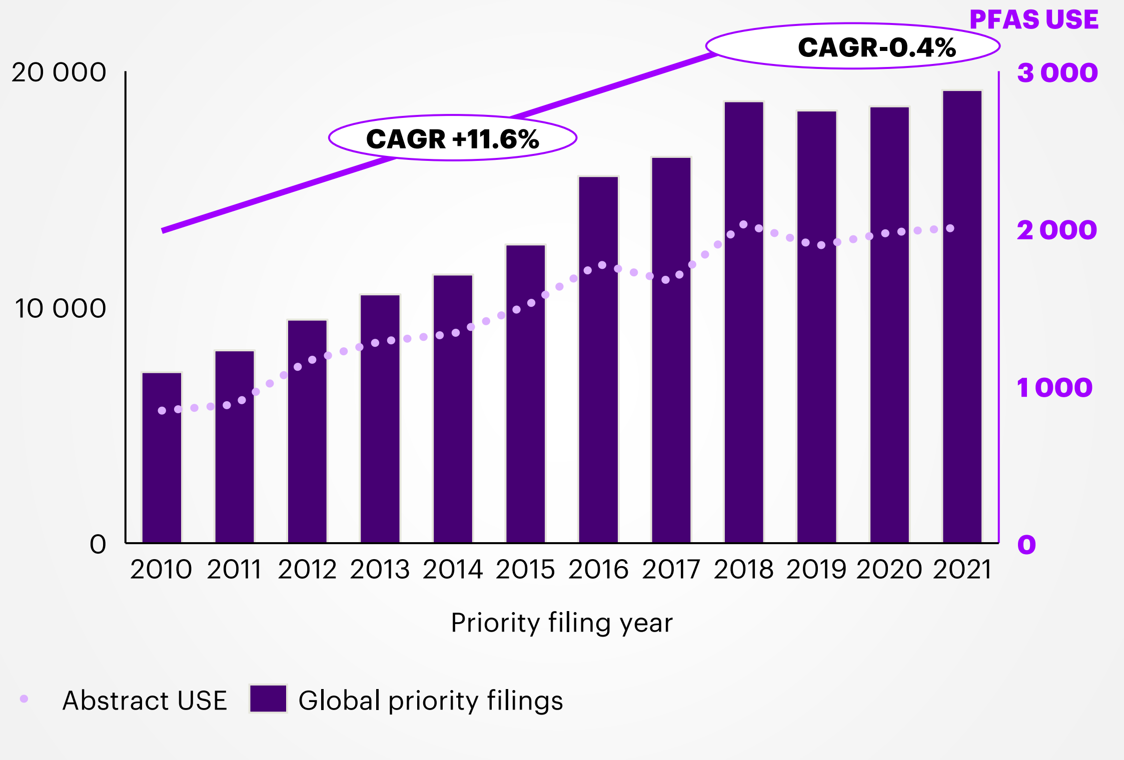
Participants reported additional challenges when looking into alternatives

Safety of future installations	Alternatives development	Production asset and supply chain adaptation	Properties of alternative materials	PFAS presence in alternative materials, equipment
• Due to their limited use, it is essential to **first test the long-term performance of existing alternatives**. Some recognized areas of reduced performances include reduced sealing performance, resulting in increased fugitive emissions • International design standards for PFAS based equipment are well established in the industry, and **standards need to be adapted/developed for alternatives**	• Process potentially lasting several years, requiring: – **R&D** – **Testing** – **Approval** from certifying bodies and clients • Alternatives should be **sustainable by design and fit for a circular economy** which requires time and effort • **A long guarantee of new products** is required by clients (typically spanning around 10 years)	• De-bottlenecking production assets: – **New sites are to be built from scratch** for some materials and equipment (e.g., high nickel alloy or ceramic piping used in niche applications) – **Important brownfield modifications on existing installations** (e.g., gaskets) • Challenges encountered in **sourcing potential alternative materials** (e.g., Tantalum)	• To achieve the desired equipment properties, the alternative materials to PFAS will also exhibit persistence, potentially introducing **comparable challenges linked to the enduring nature of PFAS**	• PFAS potentially used to improve performance of alternatives: – **Some alternatives are coated with a thin layer of PFAS** – **PFAS surfactants are used in the production of non-PFAS polymers**, identified as theoretical substitutes to PFAS polymers

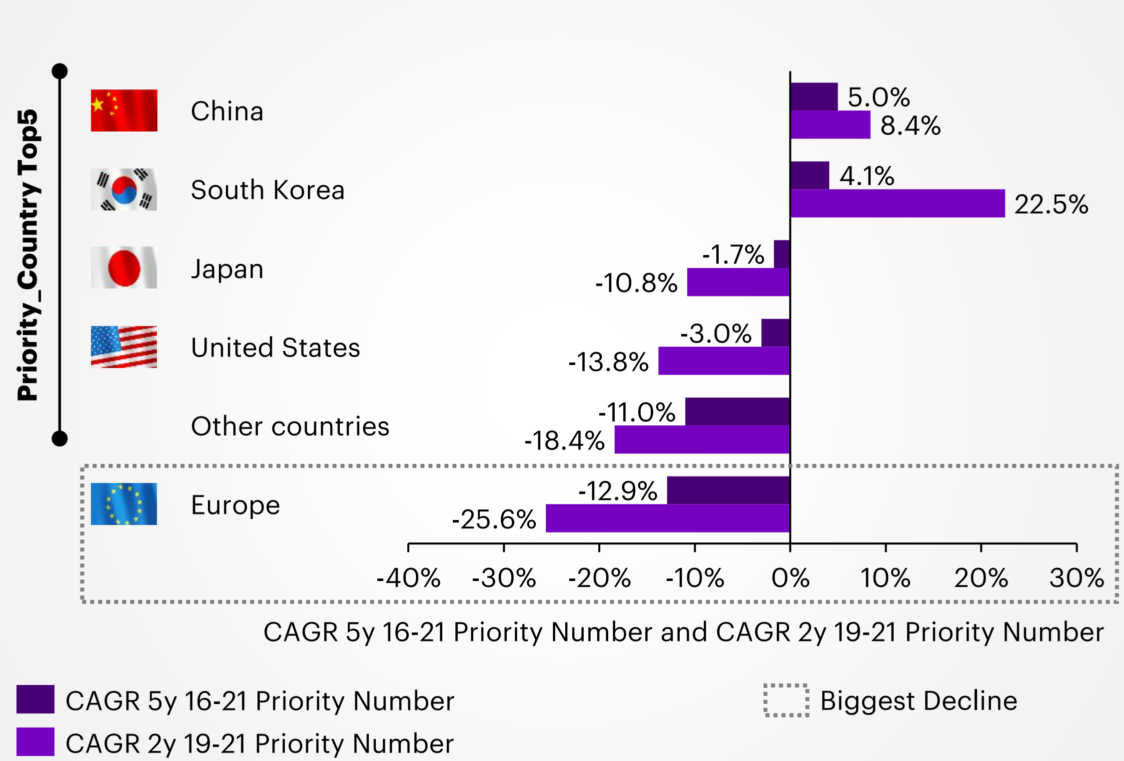
Sources: Interviews of chemical companies and suppliers, Accenture analysis

Innovation seems to move away from PFAS

Analysis of chemical industry patents filing around PFAS shows that, between 2018-2021, filing has been declining, especially in Europe



Annual priority filings per priority country, 166K priority filings
Number of priority filings – excl non relevant segments



CAGR of PFAS use in the past 5y (priority filings)

Source: Accenture Research based on Derwent Innovation™(Clarivat) e©,2023; Analysis based on set 166K patents relevant to chemical equipment filed between 2010 and 2021

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Current state of equipment waste management

Focus on **PFAS disposal phase.** Typically, these components have been used in captive systems for a long duration

PFAS disposal phase
Some companies reported specific management plans related to PFAS, including: ▪ **Periodic recycling and organized recovery of certain gaseous PFAS**, with disposal methods such as gas capture with specific treatment ▪ **Incineration or recycling of lubricants and greases**, with storage in special drums ▪ **Incineration and recycling of solid PFAS**, next to some remaining landfilling of non-hazardous waste, mostly following disposal methods like ordinary industrial waste (OIW) disposal Several companies declared that they were working on **additional PFAS-specific waste management plans**

Sources: World Health Organization, Interviews of chemical companies and suppliers, Desktop research, Accenture analysis

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Impact on companies‘ results and operations

The chemical industry is highly CAPEX intensive and operates on long life cycles and at high HSSE standards

Priorities for chemical plant design (based on companies’ inventory study)	
Safety management	• High pressures • High temperatures • Potential hazardous materials
Durability management	• Resistance to corrosion • Mechanical stress and fatigue
Return on Capital Employed	• Process optimization • Maintenance requirements • Maximize production efficiency • Minimize energy consumption

Chemical industry asset intensity	
CAPEX	• 5 to 10% of the revenue
Asset Replacement Value / Revenue	• Varying from 50% revenue for formulation business to 180% for high pressure and high intensity businesses
EBITDA	• Varying from 15% to 30%

Sources: Interviews of chemical companies and suppliers, Accenture analysis

Impact on companies' operations

The impact of a potential PFAS ban will depend on the extent and duration of potential derogations – a long lead time is needed to adapt

Existing Plants

No alternative for core equipment
- **Business case**
- **Closure**
- **Mothballing**
- **R&D** to identify alternative technologies *(10 yrs. +)*
- **Plant transformation**

Identified alternatives
- **Business case (ROCE)**
- **Closure**
- **Engineering** *(6 months – 1 yr.)*
- Plant temporary Closure
- **Plant transformation** *(6 months – 2 yrs.)*
- **Procurement** of alternative materials and **ramp up of new supply chains** *(1 – 10 yrs. depending on equipment)*
- **Client qualifications** (where relevant)

New Investments

No alternative for core equipment
- Investment in alternative locations

Identified alternatives
- **Business case, feasibility**
- Investment in alternative locations
- **Engineering**
- **Procurement**
- **Construction**

A potential ban will **halt the production of strategic materials** in Europe

Sources: Interviews of chemical companies, Accenture analysis

Impact on companies' operations

The impact of a PFAS ban on the chemical industry would be profound both for existing plants and for new investments*

Existing plants (when alternative exists)	New investments
Increased maintenance expenditure: x [2-3] vs baseline	**Higher CAPEX than existing plants:** + [15-60]% increase
Potential temporary shutdown of a plant to adapt installation with PFAS free alternatives when available: 6 months to 2 years	**Higher running cost:** increased maintenance cost x [2-3]
CAPEX requirements to modify plants: 20 to 50% of plants to be rebuilt	**Impact on plant availability****
Client requalification of processes (lost revenue): 6 months to 2 years	
Decision: Transformation of plants or shutdown **Timing:** Depending on potential derogations and timelines	**Decision:** Go/No go for new plants in Europe **Timing:** Immediate

*The estimation is based on **workshops with 10 European companies** representing chlorine chemistry, petrochemical/refinery & specialized chemistry segments

***Ratio between actual running time of a plant and planned operating time*

Sources: Accenture analysis

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List of sources of illustrations of chemical plant equipment

Process Unit's Equipment

Agitator: https://www.flexachem.com/mixing-technology/agitator/

Fans: https://us.firenews.video/culture-and-trends/axial-fans-application-features-and-characteristics/

Conveyor: https://www.albg.eu/en/know-how/conveyor-belt-systems.html

Crushers: https://www.beidoou.com/mining/5-types-crushing-equipments-for-sand-and-aggregate-production-line.html

Pump: https://fasenergo.com/catalogue/pump-and-compressor-equipment/_systems/modular-process-system-of-the-pump-counting-unit

Instruments: https://www.dolangskills.com/product/dlgk-373-process-control-training-system

DistillationTower: https://dacworldwide.com/product/distillation-column-model-training/

Dryers: https://www.indiamart.com/proddetail/air-dryers-21698567330.html

Evaporators: https://www.indiamart.com/proddetail/chemical-evaporator-machine-2225079288.html

Fired Heaters: https://heatmatrixgroup.com/company/customer-reference/refinery-cdu-fired-heater/

Steam injector: https://www.spiraxsarco.com/global/en-GB/products/boiler-controls-and-systems/steam-injectors

Heat Exchanger: http://www.cheresources.com/content/articles/heat-transfer/u-in-heat-exchangers

Mechanical Separtors: https://www.alfalaval.com/products/separation/centrifugal-separators/separators/separators-for-chemical-and-manufacturing-industries/separators-for-chemical-and-manufacturing-industries/chemical-and-green-chemicals/

Couplings (Motors): https://www.zeushydratech.com/product/dc-nd108b-omt-drive-coupling-motor-half-11kw-42mm-12mm-key/

Chemical reactor : http://www.geodrytech.com/chemical-reactor.html

Refrigeration System : https://www.coolingpost.com/features/ammonia-refrigeration-hunts-down-r22/
https://bolz-edel.com/en/chemical-vessel/

Grinders: https://www.mill.com.tw/en/category/Food-Industrial-Chemical-Mills-Grinders-Pulverizers/mills-grinders-pulverizers.html

Membranes: https://denora.com/applications/chlor-alkali-processes/Membrane-Technologies.html

Gaskets & Sealings: https://denora.com/applications/chlor-alkali-processes/Membrane-Technologies.html

Valves: https://www.fergusonindustrial.com/product/metal-seated-ball-valves/

Piping: Tube en PP pour l'industrie M104613 - Debrunner Acifer (d-a.ch)

Safety and Protection

PPE: https://www.absorbentsonline.com/spill-containment-blog/comparing-the-different-levels-of-protection-for-personal-protective-equipment-ppe/

Firefighting Foam: https://www.chemistryworld.com/news/what-to-do-with-vast-stockpiles-of-pfas-laden-firefighting-foam/4016364.article

Power and Utilities

Power Supply:
https://shop.omegascientific.com.au/index.php?route=product/product&product_id=1722

Other Products

Grease: https://lubricant-world.com/en/chemical-structure-of-greases-in-a-nutshell/

Lubricants:
https://www.bruker.com/fr/applications/industrial/chemistry/lubricants.html

Catalysts: https://medium.com/solvaygroup/catalysts-what-they-are-how-they-work-and-why-we-use-them-e4ca13295bc2

Refrigerant: https://www.britannica.com/science/Freon

List of Abbreviations & Acronyms (1/3)

ACM	Polyacrylate Rubber	**ECO**	Epichlorohydrin Rubber	**HCFC-123**	2,2-Dichloro-1,1,1-trifluoroethane
AEM	Acrylic Elastomer	**ECTFE**	Etylene Chlorotrifluorethylene	**HFC**	Hydrofluorocarbons
AFFF	Aqueous Film-Forming Foam	**EPDM**	Ethylene Propylene Diene Monomer	**HFC-134a**	1,1,1,2-Tetrafluoroethane
AI	Artificial Intelligence	**ETFE**	Etylene Tetrafluroroetylene	**HFC-143a**	1,1,1-Trifluoroethane
ASTM	American Society for Testing and Materials	**FEP**	Fluorinated Ethylene Propylene	**HFC-365mfc**	1,1,1,3,3-Pentafluorobutane
CAGR	Compound Annual Growth Rate	**FFKM**	Perfluoroelastomer	**HFO**	Hydrofluorolefins
CAPEX	Capital expenditure	**FK-5-1-12**	Fire Supressant Fluid	**HFO- 1233 zd**	1-Chloro-3,3,3-trifluoropropene
CEFIC	European Chemical Industry Council	**FKM**	Fluoroelastomer	**HFO-1234yf**	2,3,3,3-Tetrafluoropropene
CO2	Carbone Dioxide	**FM200**	HFC-227 ea	**HFO-1336mzz**	Cis-1,1,1,4,4,4-hexafluoro-2-butene, cis-CF3CH=CHCF3
CPE	Chlorinated Polyethylene	**FTI**	Fluorotelomer-based technology	**HIW**	Hazardous Industrial Waste
CR	Polychloroprene Rubber	**FTO**	Fluorine-doped Tin Oxide	**HNBR**	Hydrogenated Nitrile Butadiene Rubber
CSM	Chlorosulfonated Polyethylene	**FVQM**	Fluorosilicone Rubber	**HSE**	Health, Safety and Environment
EBITDA	Earnings before interest, taxes, depreciation, and amortization	**HCFC**	Hydrochlorofluorocarbons Hydrofluorocarbons	**HSSE**	Health, Safety, Security and Environment

List of Abbreviations & Acronyms (2/3)

IIR	Isobutylene Isoprene Rubber	**PFAS**	Per and polyfluoroakyl substances	**PPE**	Personal Protective Equipment
IoT	Internet of things	**PFBA**	Perfluorobutanoic Acid	**PPS**	Polyphenylene Sulfide
MSDS	Material Safety Data Sheet	**PFBS**	Perfluorobutanesulfonic Acid	**PPV**	Poly(p-phenylene vinylene)
NBR	Nitrile Butadiene Rubber	**PFC**	Perfluorinated Compound	**PSU**	Polysulfone
Ni	Nickel	**PFCA**	Perfluorocarboxylic Acid	**PTFE**	Polytetrafluoroethylene
NR	Natural Rubber	**PFNA**	Perfluorononanoic Acid	**PVC**	Polyvinyl Chloride
OECD	Organization for Economic Cooperation and Development	**PFOA**	Perfluorooctanoic Acid	**PVDF**	Polyvinylidene Fluoride
OIW	Ordinary Industrial Waste	**PFOS**	Perfluorooctanesulfonic Acid	**R&D**	Research and development
PCTFE	Polychlorotrifluoroethylene	**PFPAE**	Perfluoropolyakylether	**R-401A**	Blend of HCFC-22, HFC-125, and HCFC-124
PEEK	Polyether Ether Ketone	**PFPE**	Perfluoropolyether	**R-404A**	Blend of HFC-125, HFC-143a, and HFC-134a
PEI	Polyetherimide	**PFSA**	Perfluorosulfonic Acid	**R-407**	Blends of HFC-32, HFC-125, and HFC-134a
PFA	Perfluoroalkyl	**pH**	Potential of hydrogen	**R-410A**	Blend of HFC-32, and HFC-125
PFAE	Perfluoroalkyl Ether	**PP**	Polypropylene	**R-417A**	Blend of HFC-125, and HFC-134a

List of Abbreviations & Acronyms (3/3)

R-422D	Blend of HFC-125, HFC-134a, and isobutane	**SFPM**	Synthetic Film-forming Multi-purpose Multi-foaming
R-427A	Blend of HFC-32, HFC-125, HFC-134a and HFC-143a	**SiC**	Silicon carbide
R-448A	Blend of HFC-32, HFC-125, HFC-134a, HFO-1234yf, and HFO-1234	**SST**	Stainless Steel
R-449A	Blend of HFC-32, HFC-125, HFC-134a, and HFO-1234yf	**SVR**	Stratified glass resin
R-452A	Blend of HFC-32, and HFC-125, and HFO-1234yf	**Ta**	Tantalum
R-507	Blend of HFC-125 and HFC-143a	**Ti**	Titanium
R-513A	Blend of HFO-1234yf and HFC-134a	**UL**	Underwriters Laboratories
R-gas	Refrigerant gas	**UV**	UltraViolet
ROCE	Return on Capital employed	**VDF**	Vinylidene Fluoride
SBR	Styrene Butadiene Rubber	**VQM**	Vinyl Methyl Silicone
SFA	Semi-Fluorinated Alkane	**Zr**	Zirconium