

PFAS Study in Chemical Plants and Refineries Equipment

France

Final Report

July 2023

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Executive Summary (1/4)

- PFAS are a large group of substances, both **polymeric and non-polymeric**, containing **carbon-fluorine bonds (C-F)** which is considered to be the strongest in organic chemistry, resisting heavily to degradation
- OECD lists around **5000* PFAS** which are scientifically referenced by their chemical structure category name (e.g., polytetrafluoroethylene), but better known by industrials by their abbreviations (e.g., PTFE) or brand name (e.g., Teflon)
- While encompassing a very diverse portfolio of products, PFAS are predominantly used as raw material in chemical synthesis and are mainly found in solid form in equipment. Solid **PFAS (mainly fluoropolymers)** represent a small portion of the total PFAS substances (**~5%**)
- The future European **project to restrict PFAS** (Perfluoroalkyl and Polyfluoroalkyl Substance) in chemical plants equipment will have implications on the operations of existing assets and decision to invest in new ones
- The chemical and refining industries are **highly CAPEX intensive** and need to operate with **high HSE standards**, therefore there is a priority to operate with equipment fit for security, that can be used over a long period of time and maximize the return on capital employed
- The **impact of a PFAS ban on the chemical and refining industries would be massive** as **few PFAS-based materials are used extensively** in core equipment of chemical plants and refineries:
 - **Technical substitutes for several PFAS based equipment are not available** (e.g. membranes, ...), **or do not ensure the same level of safety performance** (e.g. joints, ...), hence several plants could no longer operate
 - For existing plants, impact of one-off cost represents up to **6 months to 1 year of revenue**, and a reduction of **20-30% of EBITDA impact**. This combines the **required investments to replace core equipment of plants** as well as the **revenue losses linked to the interruption of production over a period of 6 months to 2 years**
 - For new plants, **higher CAPEX and increased running cost could deter new investments in France**

Executive Summary (2/4)

- In addition, where technical substitutes for materials used in chemical plants exists, the **supply industry is not structured to supply required volumes over a short period of time** and the timing to validate the feasibility at industrial scale would take several years
- **Identifying PFAS in industrial equipment is a task that has been proven to be difficult to conduct**, even for big chemical companies, mainly due to (i) the multiplicity & diversity of equipment that composes a chemical plant, (ii) the limited familiarity with the bill of material as equipment are predominantly specified by their functional performance, and (iii) the limited focus of the industry on the topic
- The chemical and refining industries have a limited set of PFAS used in plants, **~30 molecules**. The main ones are fluoropolymers (plastics and elastomers), lubricants, foams, refrigerant gas. The use of these materials is omnipresent in chemical and refining plants
- Many equipment containing PFAS are **similar for the whole industry** (piping, pumps, seals, refrigerant gas, etc.), while some are **specific to certain chemical processes** (membrane, mixer, etc.). Most of the uses are in core assets of the plants, close to the process
- Several properties are sought in fluoropolymers, the predominant category of PFAS found in chemical equipment:
 - **Chemical resistance** to a very corrosive environment
 - Strong **mechanical properties**
 - **Thermal resistance** at high temperature
- PFAS in joints, pipes, valves and refrigerant gases in chemical plants are chosen for one or more of these properties
- During the factory operation phase, the risks of accidental release in the environment varies by type of PFAS (e.g solid vs gaseous or liquid state, in contact with products or water,...)
- Some chemical companies that serve specific industries (e.g., semiconductors for microelectronics) requiring high level of purity in the final product are integrating into their operations the control of the presence of any undesirable substances at the end of their process

Executive Summary (3/4)

- Regarding the end-of-life of PFAS products/equipment, **some measures exist for gases, while the disposal of solid PFAS is not subject to specific control**
- The **chemical industry and its suppliers have started investigating alternative to PFAS materials** used in plant, providing similar properties (durability, resistance, ...)
- **For some equipment, there currently are no identified viable alternatives** (e.g., membrane, diaphragm)
- **For some use cases only**, technical alternatives to PFAS exist for some materials in the form of:
 - **Replacement of Fluoropolymers: other polymers, Specialty metals**, other materials (e.g., glass, ceramics, ...)
 - **Non-fluorinated gases** for refrigerants
- In particular, the industry has identified some potential substitutes for the following PFAS equipment working only for a limited number of use cases:
 - **Joints**: metallic (nickel), graphite, organic/mineral fibers
 - **Piping**: thermoplastics, Hastelloy, glass lining, nickel, titanium
 - **Valves**: polyethylene, Hastelloy, EPDM, Vespel
 - **Refrigerant gas**: Ammonia, CO2, propane/methane
 - **Coating**: PPV, Epoxy, Polyester, melamine
- However, **they often do not match all the properties of the original substance**, making them less desirable. In particular, they do not offer the same level of safety and environmental protection

Executive Summary (4/4)

- Beyond the material performance, the alternatives have other drawbacks:
 - **Safety** of the future installations to be demonstrated
 - **Long alternative development process** (R&D, testing, approval from client, confidence from supplier to provide same level of guarantees)
 - **Production tools and supply chain adaptation to cope with sharply increased volumes**
 - **Possible same persistence characteristic** of alternative materials with similar properties to PFAS
 - Some identified alternatives containing **traces of PFAS** (voluntarily or involuntarily)
- Many challenges are identified with a ban of PFAS in industrial equipment:
 - **No known alternatives** to date for some equipment and unfavorable performance of alternatives identified
 - **Insufficient supply chain maturity** for manufacturing of PFAS free equipment with little to no capacity for alternative identified
 - Substantial impact on **direct costs (maintenance)** and impact on **utilization** (more frequent failure/maintenance activities)
 - **High CAPEX required** to transform plants linked to the use of PFAS and **severe commercial impact** linked to **interruption of production**
- Workshops with chemical and refining companies allowed to identify potential improvement of PFAS management in plants:
 - Better **traceability of PFAS** in equipment like type, quantity, origin etc. (e.g in a material passport)
 - More stringent **control of PFAS degradation** and **end-of-life management**
 - Stronger **collaboration between equipment suppliers and chemical companies** to develop and test new alternatives to PFAS materials

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Accenture assessed PFAS use in French chemical and refining plants, alternatives and potential impacts of a ban

Report based on workshops, interviews, and Accenture analysis

Scope of the study

- **The French Chemical and Refining sectors** are covered, in particular: Chlorine chemistry, Petrochemicals / Refinery, Specialized (incl. Fine) chemistry
- **PFAS inventory and alternative analysis:**
 - Identification of the equipment containing PFAS in chemical and refining plants
 - Identification of the different type of PFAS and their properties
 - Exploration of the potential substitution solutions for affected equipment
- **Expected impact** of the regulation:
 - Operational
 - Economic
 - Social & Environmental

Methodology

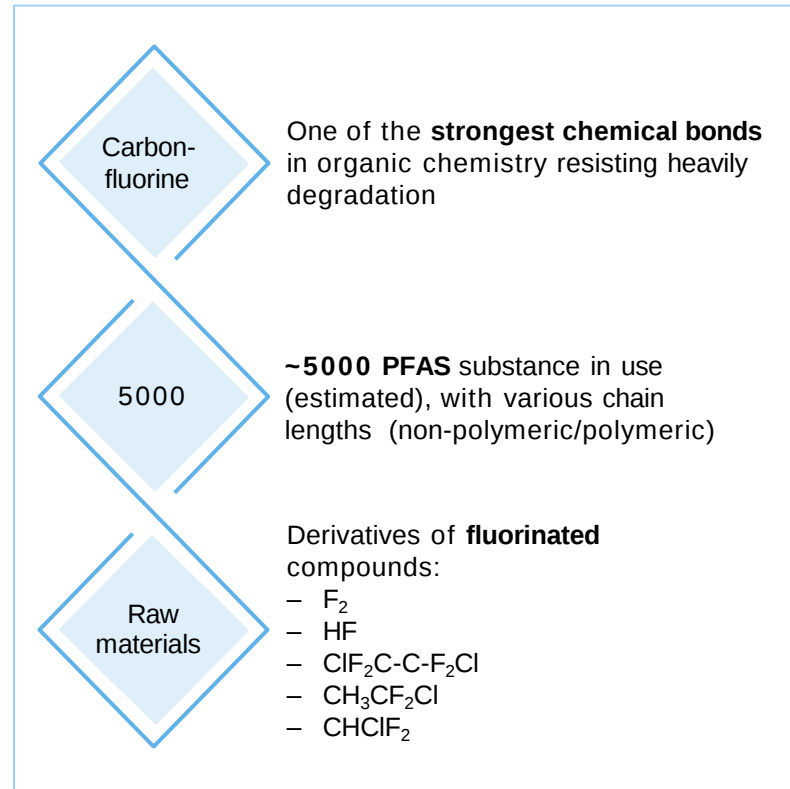
- **Workshops** with 10 companies part of the diverse French chemical industry landscape
 - 1st workshop: focus on the inventory of industrial equipment containing PFAS on selected industrial plants
 - 2nd workshop: analysis of the impact of a PFAS ban on the selected industrial plants
- **+25 interviews** conducted with **chemical equipment manufacturers & associations** (joints/gaskets, piping, valves, refrigerant gas, painting/coating, electronics)
- Accenture's research and analysis

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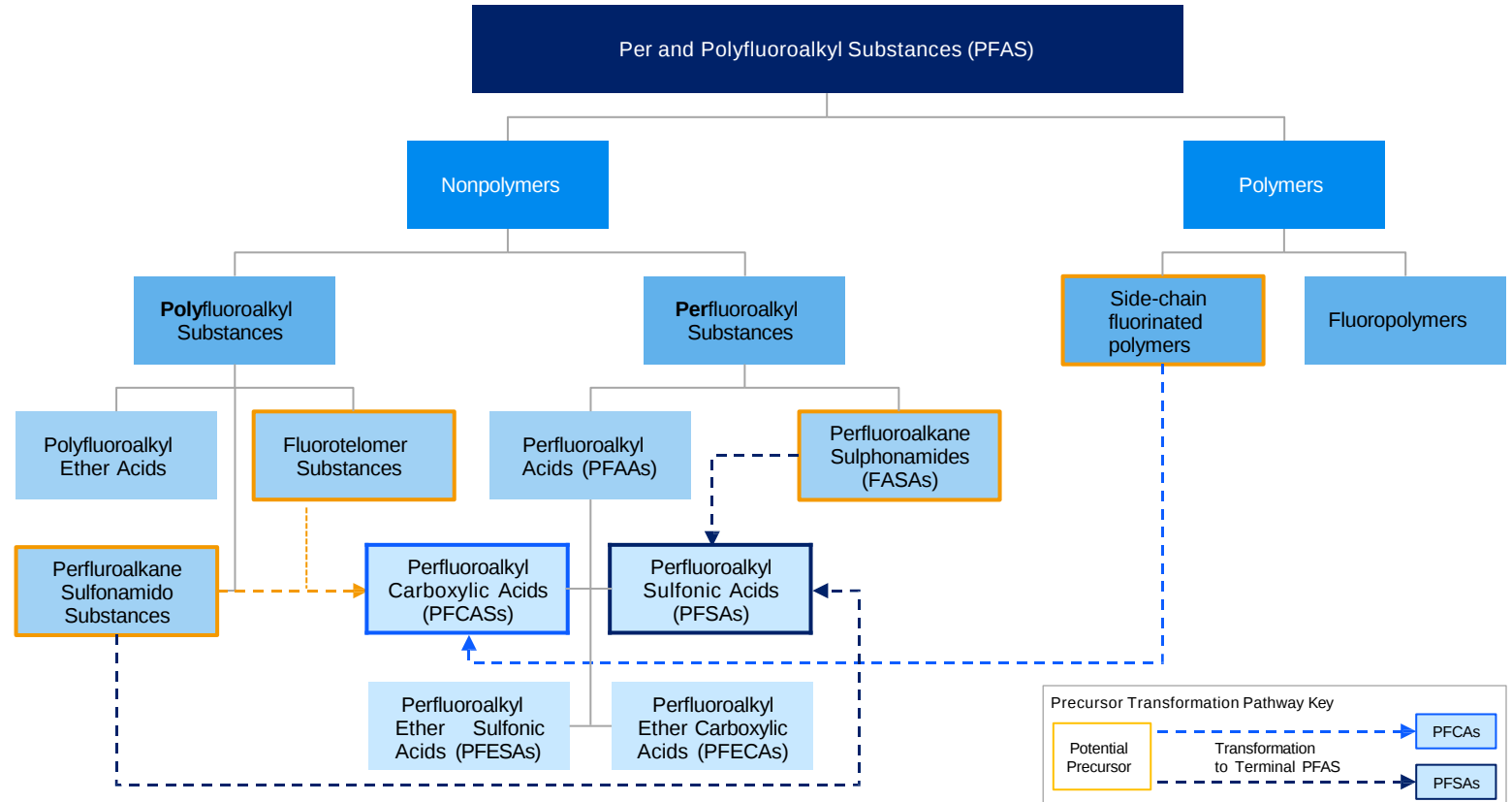
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PFAS are a large group of substances, both polymeric and non polymeric, containing the strongest Carbon-Fluorine bond

Key elements

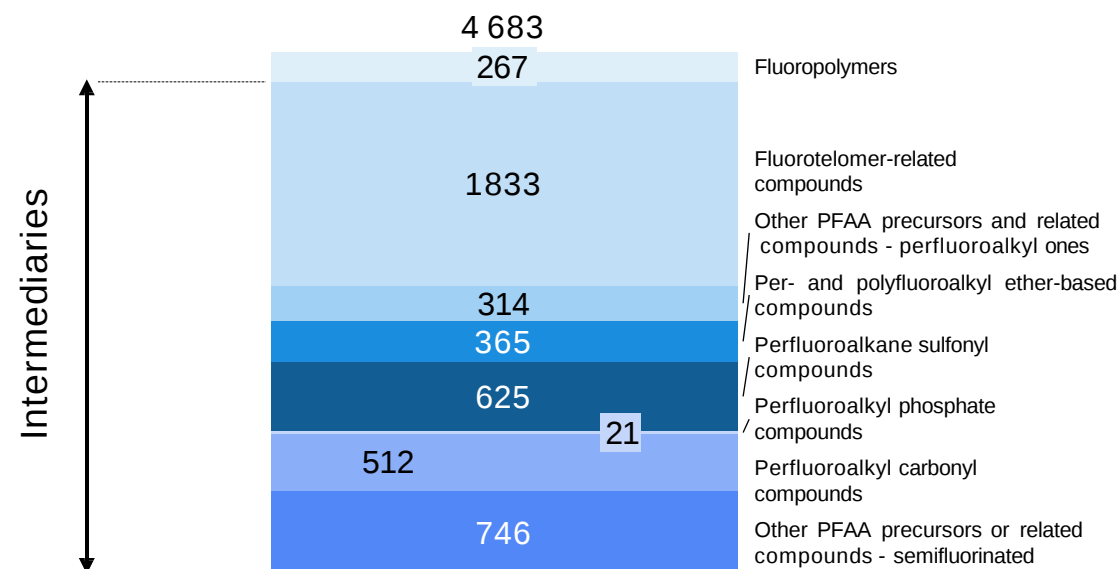


PFAS product tree (simplified)¹

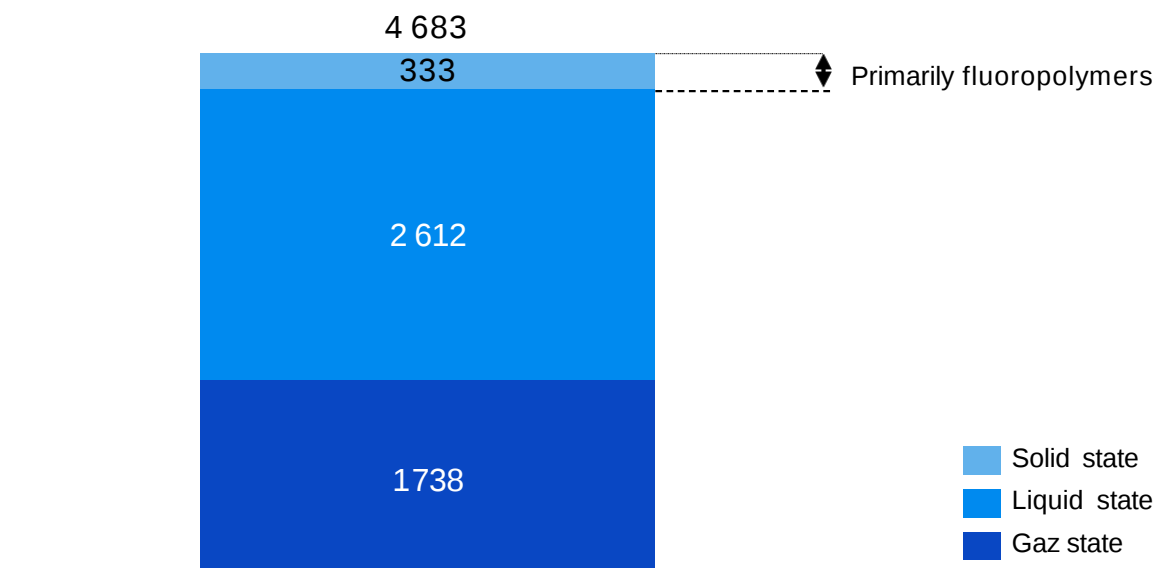


Predominantly used as raw material in chemical synthesis, PFAS are mainly found in solid form in industrial equipment, primarily as fluoropolymers

PFAS distribution by main category



PFAS distribution by state



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

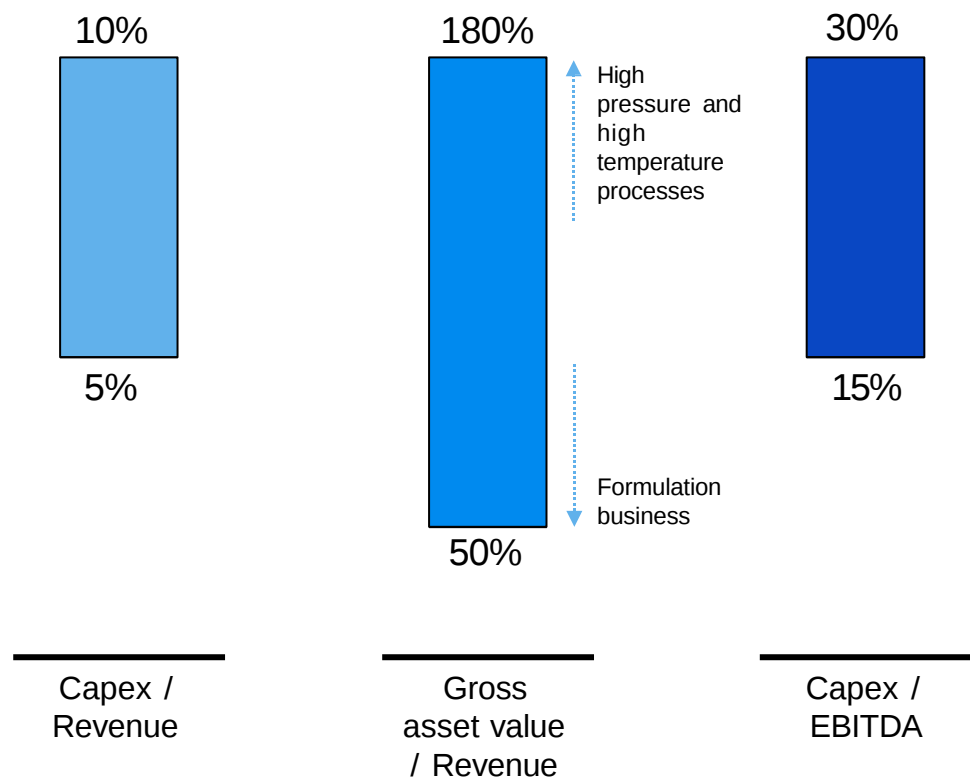
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The chemical and refining industries are generally highly CAPEX intensive and needs to operate with high standard HSE

Characteristics of chemical industry: strong difference across segments

Chemical industry asset intensity



Priorities for Chemical Plants Design

Safety management

- High pressure
- High temperatures
- Potential hazardous materials

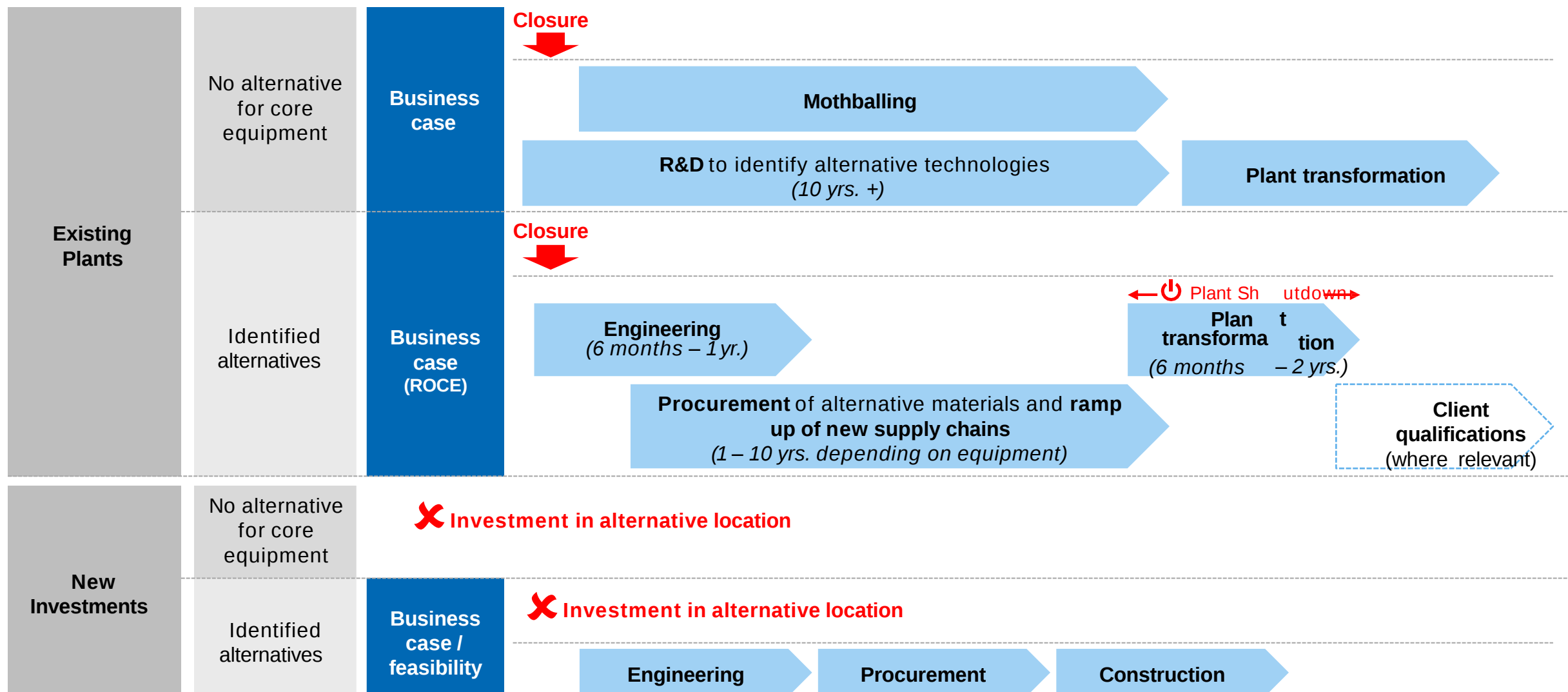
Durability management

- Resistance to corrosion
- Mechanical stress and fatigue

Return on Capital Employed

- Process optimization
- Maintenance requirements
- Maximize production efficiency
- Minimize energy consumption

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



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

Expected impact from PFAS ban on chemical and refining plants in France

Existing plants (when alternative exists)

Increased maintenance expenditure: x [2-3] vs baseline

Potential temporary shutdown of plant to adapt installation with PFAS free alternatives when available: 6 months – 2 years

CAPEX requirements to modify plants: 20 to 50% of plant to be rebuild

Client requalification of process (lost revenue): 6 months to 2 years

Decision: Transformation of plant or shutdown

Timing: Depending on potential derogations and timeline

New investments

Higher CAPEX than existing plants: + [15-60]% increase

Higher running cost: increased maintenance cost x [2-3]

Impact on plant availability

Decision: Go / No go for new plant in Europe

Timing: Immediate

For existing plants, impact of one-off cost could represent up to 6 months to 1 year of revenue and 20-30% of EBITDA impact

Expected impact from PFAS ban on chemical and refining plants in France

Dimension	Impact	Baseline	Financial estimate
Increased maintenance expenditure: [2-3] x baseline	x[2-3] higher maintenance cost	- Maintenance cost index: maintenance cost / gross asset value = 1.5-3% - Asset intensity: Gross asset / revenue = x [0.5-2]	3-5% of revenues every year (approximatively 20-30% of EBITDA)
Potential shutdown of plant to adapt installation with PFAS free alternatives when available	6 months – 2 years shutdown	- Loss of revenue and gross margin = 50-100% - Gross margin = 30-50% of revenue	- One off impact: 25-50% of revenue over 6 months to 2 years - Potential longer-term loss of clients due to supply interruption
CAPEX requirements to modify plants	20-50% of plant to be rebuild with higher cost materials	- Asset intensity in chemical: gross asset value / revenue = x [0.5-2] 15-60% CAPEX increase for PFAS free alternative (when existing)	One off impact: 30-50% of revenue for medium asset intensity business
Client requalification of process (loss of revenue): 6 months to 2 years	Loss of revenue or reduction in gross margin due to the sale of products to alternative channels	Highly variable depending on the customer segment (commodity vs specialties in highly demanding sector e.g., semi conductor)	To be confirmed

Potential decision to shut down plant or part of the plant due to unfavorable ROI

For new plants, higher CAPEX and increased running cost could deter new investments

Expected impact from PFAS ban on chemical and refining plants in France

Dimension	Impact	Baseline	Financial estimate
CAPEX requirements to modify plants	15-60% CAPEX increase for PFAS free alternative (where existing) *	Asset intensity in chemical (gross asset / revenue) = [0.5-2]	- One off impact: 15-60% of revenue for medium asset intensity business - Potential decision to build plant in alternative location, especially for export business
Increased maintenance expenditure: x 2-3** vs baseline	x [2-3] higher maintenance cost	- Maintenance cost index: maintenance cost / gross asset value = 1.5-3% - Asset intensity: Gross asset / revenue = [0.5-2]	3-5% of revenue every year (~20% of EBITDA)

Potential decision to relocate the investments abroad

The chemical industry highlights the potential need to close sites in order to comply with an eventual PFAS-ban regulation

Operational impact

- « [50-60]% of the lined piped and accessories of the site need to be **replaced**. It will be very difficult for us in terms of cost and time if we face an immediate ban »
- « On some occasions, replacements of equipment with substitutes are **possible** »
- « If alternatives exist, it will take up to **[1-2] years** to replace all equipment and get the regulatory validations »
- « Depending on the substitute, maintenance will have to be **more frequent** (from 1 every three years to 1 every year), and therefore **more costly** »
- « If there is an immediate **ban on all electrolysis membranes**, we will have to shut down all the facilities on the platform »
- « **Customer qualification** will last between 6 to 18 months to confirm that product quality is not affected by the change »
- « The difference in weight with PFAS-free equipment could compel us to undertake **reinforcement work on the structures** of our installations »
- « Since all the facilities are interdependent, we will have to **shut down** the whole plant »

Economic impact

- « If we obtain a **time derogation**, we will be able to **smooth the CAPEX** over years. Otherwise, the cost will be unbearable »
- « The activities to discontinue represent a turnover of **50-100M€** in 2022 »
- « It might be more convincing to **rebuild** "PFAS free" plant out of scratch then replacing an existing site with PFAS »
- « Decrease in turnover caused by **relocated investments** and loss of clients »
- « Substitutes for gaskets **are 2 times more expensive** than PTFE, substitutes for equipment made or coated in PVDF are **5 times more expensive** and substitutes for equipment with small parts in PFAS are **3.5 times more expensive** »
- « 1 year of shutdown will cost us **1 year of turnover** »

Social and Environmental impact

- « The **totality of jobs** on the site will be affected by a short-term PFAS ban »
- « An immediate ban will **impact our employees**: up to 240 direct jobs and 1000 indirect jobs could be lost »
- « Review of all **waste treatment processes** and introduction of **emission controls** with analytical monitoring of water and air »
- « Hazard study will need to be **revised** »
- « Reinforced **medical monitoring** of personnel »

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Identifying PFAS in chemical and refining plants is a challenge for many players

Limited focus from Engineering and Regulatory Teams on PFAS used in industrial equipment

- Engineering responsibilities often lie within **external parties**
- Equipment and material selection prioritize **functional specification** such as temperature, pressure and chemical compatibility requirements over PFAS presence
- **Regulatory teams** primarily concentrate on assessing the **compliance and safety** of raw materials and additives used in final products

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 ...

Many equipment containing PFAS are similar for the whole industry while some are specific to certain chemical processes

Core equipment containing PFAS identified during the workshops and through report analysis*

Equipment containing PFAS common to all companies**

Category of equipment									
Process units			Other Products		Power, Utilities & Electronics			Safety and Protection	
Joints/ Gaskets ✓	Valves ✓	Vessels ✓	Refrigerant gas ✓	Grease ✓	Electric cables/ wires ✓	Semi- conductor ✓	Batteries ✓	PPE ✓	Firefighting Foams ✓
	Piping ✓	Pumps ✓	Paint*** ✓	Lubricants ✓		Measuring instrument ✓	Circuit Breakers ✓		

Equipment containing PFAS specific per company

Company groups	Analytical equip.	Membrane	Filter	Balloon	Ejector	Reactor	Heat Exchanger	Laboratory Equip.	Decanter	Hydrolyser	Separator	Agitator	Mixer	Expansion pot	Emulsifier	Micronizer
Chlorine chemistry	#1															
	#2	✓	✓													
Petrochem/ Refinery	#3			✓	✓	✓	✓									
	#4															
Specialized chemistry (incl. fine chemicals)	#5	✓						✓								
	#6	✓				✓										
	#7	✓				✓	✓									
	#8			✓		✓	✓		✓	✓	✓					
	#9			✓		✓						✓	✓	✓		
	#10				✓										✓	✓

Companies identify 3 groups of PFAS, representing ~30 types of PFAS - a small subset of the overall PFAS landscape

Identified PFAS substances



Solid State

Fluoropolymers

- FKM (*Viton, Tecnoflon, Dyneon,...*)
- FFKM (*Kalrez, Tecnoflon,...*)
- PTFE (*Teflon, Gylon*)
- FEP
- PFA
- PVDF (*Kynar, Hylar, Solef*)
- ETFE
- PCTFE
- ECTFE

PFAS compounds

- PFSA**
- PFCA**



Liquid State

Lubricants

- PFAE
- PFPE
- PFPPE
- PCTFE (*Voltalef*)

Firefighting foams

- C6 Foams (SFPM***)



Gaseous State

Refrigerant gases

- R22
- R134 a
- R404 a
- R407 a
- R407 c
- R410
- R427 a
- R507

Different types of PFAS can be found in various equipment, depending on their use (1/2)

Identified PFAS in process units' equipment during the workshops and through report analysis

Equipment		PTFE	PVDF	PFA	FFKM	FKM	PCTFE	FEP	ECTFE	PFSA	PFCA
Process unit equipment	Gaskets	✓	✓	✓	✓	✓	✓	✓	✓		
	Valves	✓	✓	✓	✓	✓	✓	✓	✓		
	Vessels	✓	✓	✓	✓	✓	✓		✓		
	Piping	✓	✓	✓	✓	✓	✓		✓		
	Pumps	✓	✓	✓	✓	✓	✓	✓	✓		
	Reactors		✓					✓			
	Membranes	✓	✓	✓		✓	✓	✓		✓	✓
	Ejectors	✓	✓								
	Laboratory Equipment	✓	✓	✓			✓	✓			
	Filters	✓	✓	✓		✓		✓	✓		
	Agitators		✓								
	Balloons	✓							✓		
	Decanter		✓								
	Hydrolyser		✓								
	Micronizer	✓									
	Separator		✓								
	Heat Exchanger	✓									
	Analytical Equipment	✓	✓	✓		✓		✓	✓		
	Expansion Pot		✓								
	Mixer		✓								

Different types of PFAS can be found in various equipment, depending on their use (2/2)

Identified PFAS in three other categories of equipment during the workshops and through report analysis

Equipment		PTFE	PVDF	PFA	FFKM	FKM	PCTFE	FEP	ECTFE	ETFE	PFPE	PFAE	PFPAE	SFPM*
Other Products	Lubricant Grease						✓				✓	✓	✓	
	Paint for buildings & external structure	✓	✓											
Power, Utilities and Electronics	Electric wires	✓		✓	✓	✓	✓			✓				
	Circuit Breakers	✓												
	Semi-conductors	✓	✓											
	Batteries		✓											
	Measuring instruments									✓				
Safety and Protection	PPE	✓	✓	✓		✓		✓	✓					
	Firefighting foams													✓

Different types of PFAS can be found in various equipment

Identified PFAS during the workshops and through report analysis*

Type of industrial		Fluoropolymers									Lubricants/ Grease	R-gas	Fire- fighting Foams	Main equipment
		PTFE	PVDF	PFA	FFKM	FKM	PCTFE	FEP	ECTFE	PFSA				
Chlorine chemistry	#1	✓	✓	✓	✓	✓		✓			✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE
	#2	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE Pumps, Analytical equip., Membranes, Filters
Petrochem/ Refinery	#3	✓				✓		✓			✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE Balloons, Ejectors, Reactors, Heat Exchanger
	#4	✓		✓	✓	✓	✓	✓			✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE Pumps
Specialized Chemistry (incl. fine chemicals)	#5	✓	✓	✓			✓	✓			✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE Pumps, Membranes, Laboratory equip.
	#6	✓	✓	✓		✓					✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE Pumps, Membranes, Reactors
	#7	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	Gaskets, Piping, Valves, Vessels,PPE Membranes, Heat Exchanger, Reactors
	#8	✓	✓	✓		✓		✓			✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE Decanter, Heat Exchanger, Hydrolyser, Reactors, Filters, Separator
	#9	✓	✓	✓				✓			✓	✓	✓	Gaskets, Piping, Valves, Vessels, PPE Pumps, Agitator, Ejectors, Mixer, Filters, Expansion Pot
	#10	✓	✓	✓	✓	✓		✓	✓			✓	✓	✓

Several properties are sought in Fluoropolymers, making them the predominant category of PFAS found in chemical equipment

Properties of PFAS



Chemical Properties

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, limited product contamination (i.e., no impurities)

Resistance to permeation and capacity to prevent migration of gases, liquids, and chemicals through material



Thermal Properties

Wide operating temperature range:

As example, PTFE has a temperature range of [-240–260] °C and can withstand high temperatures without degradation



Mechanical Properties

Resistance to pressure: Some chemical processes require high pressure

High tensile strength:

Can withstand mechanical stress and deformation

Low friction coefficient:

Non-stick and lubricants properties

PFAS joints, pipes, valves and refrigerant gases in chemical plants are chosen for one or more of these properties (1/4)

Focus on joints



Type of joints

Static joints

Dynamic joints

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 (-260 to +300 °C) • Used when the application goes beyond the limits of traditional lip seals

PFAS joints, pipes, valves and refrigerant gases in chemical plants are chosen for one or more of these properties (2/4)

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 -200 to +260°C	• Chemical resistance: highly resistant to chemicals, rot-proof and mildew-proof • Thermal resistance: operating temperatures from -20°C to +150°C • Other properties: insensitive to ultraviolet rays, Highly waterproof, Non-flammable (UL V0)

PFAS joints, pipes, valves and refrigerant gases in chemical plants are chosen for one or more of these properties (3/4)

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: $-30 < T < 210^{\circ}\text{C}$ • Mechanical resistance: vacuum-proof lining	• Chemical resistance: resistant to acid and basic liquids • Thermal resistance: $-30 < T < 120^{\circ}\text{C}$

PFAS joints, pipes, valves and refrigerant gases in chemical plants are chosen for one or more of these properties (4/4)

Focus refrigerant gas



Types of F-gases

Common functions	Act as cooling agent in industrial applications by having a low boiling temperature
Types of PFAS present	e.g., R-134a, R-410a, R22, R323, R404a, R407 a, R407c, R427a, R507
Desired properties	• Heat transfer capacity • Pressure-drop performance • Chemical resistance: non-corrosive, non-flammable • Boiling temperatures match required levels

Risks of accidental release of PFAS in the environment varies by type of PFAS

Focus on factory operation phase

PFAS State	PFAS	PFAS in contact with product	Release risk	Comments
Solid	Fluoropolymers: • Fluoroelastomers • Fluoroplastics	✓	1. Environmental factors - Degradation over time: a. Heat b. Erosion c. Chemical reaction or mechanical stress	• Release of microplastics • Leaching
Liquid	• Lubricant • Grease • Firefighting Foams	X	1. Accidental spills or leaks during storage, transportation or handling 2. Evaporation due to over-heating	• Lubricant/grease mainly in contact with chemical equipment if released accidentally during the process • Firefighting foam is released in the air after usage
Gaseous	• Refrigerant gas	X	1. Leaks	• Decomposition of gas in environment

Few companies measure the presence of PFAS in their products

Company Groups		Measurement in final product	Measurement in waste water
Chlorine chemistry	Company #1	X	Planned with evolution of regulation
	Company #2	X	
Petrochemicals /Refinery	Company #3	X	
	Company #4	X	
Specialized chemistry (incl. fine chemicals)	Company #5	X	
	Company #6	X	
	Company #7	Particle presence in the final product	
	Company #8	X	
	Company #9	X	
	Company #10	X	

- One company interviewed serving specific industry (semiconductor) mentioned that they **measure the presence of particles in the final product** at ppb levels and **that no PFAS traces are found**
- For a typical equipment (piping), the **degradation of the PFAS** is assessed by **visual check** of the damage to the pipe (perforation of the pipe due to permeation of chemical product through PFAS potentially creating leakage)

For end-of-life, some measures exist for gases and liquids, while solid PFAS elimination is not controlled specifically

Focus on PFAS disposal phase

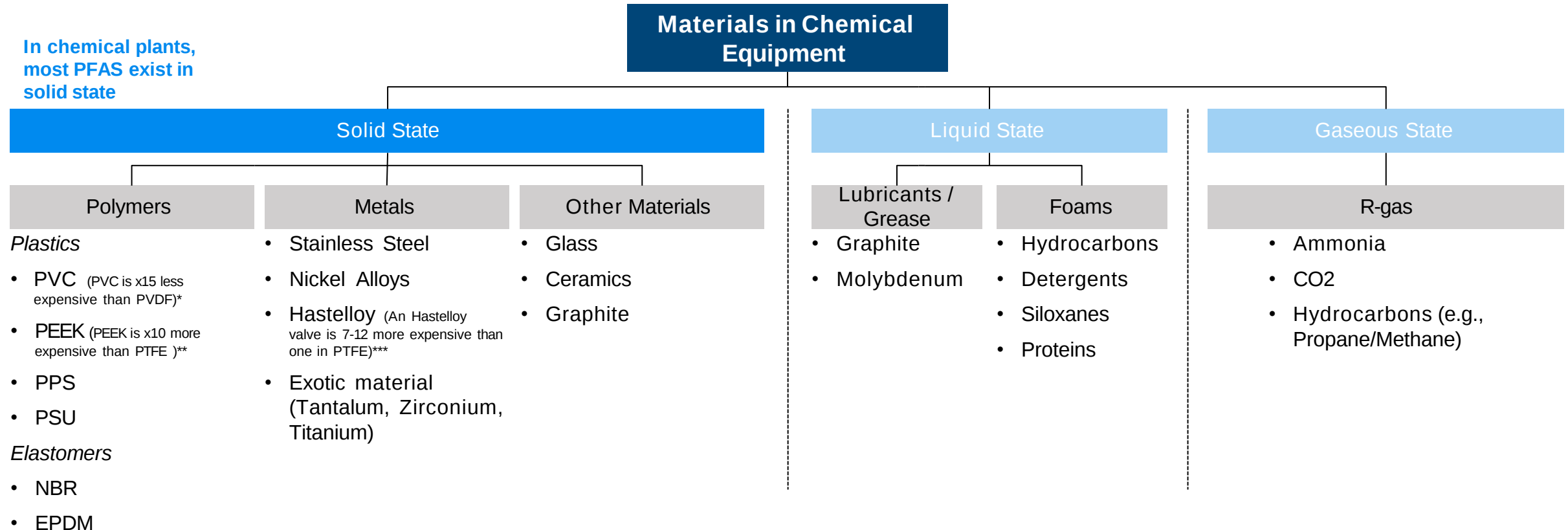
PFAS State	Disposal method in chemical plant	End of Life	Measure specific in place	Comments
Solid	1. Ordinary Industrial Waste (OIW) i. Metallic → Metal-specific waste bucket ii. Common → Ordinary waste bucket 2. Hazardous Industrial Waste (HIW) ✕ → Equipment-Specific/PFAS-Specific	• Incineration • Recycling • Specific treatment	X	• Release of pollutants and ash residues into the atmosphere if incinerated
Liquid	1. Stocked in special drums	For lubricants/grease: • Incineration • Recycling: regeneration to obtain a new lubricant	✓	• Regulation for the recycling of lubricants • Release of pollutants and ash residues into the atmosphere if incinerated
Gaseous	1. Gas capture with specific treatment	• Mandatory Maintenance • Periodic recycling • Organized recovery	✓	• EU F-gas regulation in place • Gas treatment is subcontracted to specific companies

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PFAS have technical alternatives for some applications, coming from different material classes

Focus on identified PFAS alternatives by categories



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

However they often do not match all the properties of the original substance, making them less desirable (1/3)

Other polymers: focus on Thermoplastics

Thermal Resistance

	Symbol	Material name	Max. working T. [°C]		PEEK	PTFE
Fluoropolymer	PTFE	Polytetrafluoroethylene	260	Hydrochloric acid	Fair	Good
	PFA	Perfluoroalkoxy polymer	150	Sulfuric acid	Poor	Good
	PVDF	Polyvinylidene fluoride	150	Nitric acid	Poor	Good
Alternatives	PEEK	Polyetherketone	250	Tetrahydrofuran (THF)	Poor	Good
	PPS	Polyphenylene sulfide	240	Dimethyl sulfoxide (DMSO)	Poor	Good
	PSU	Polysulfone	150	Chloroform	Poor	Fair
	PEI	Polyetherimide	170			

Table 1: List of selected heat-resistant plastics¹

Table 2: Chemical resistance PEEK | PTFE ²

In terms of **working temperatures** alone, there are **alternative plastics available** for certain PFAS.

For instance, **PEEK is a possible alternative for PTFE** in a very large domain of chemicals **but with limitations in some applications** (e. g. in strong or oxidizing acid and in some solvents)

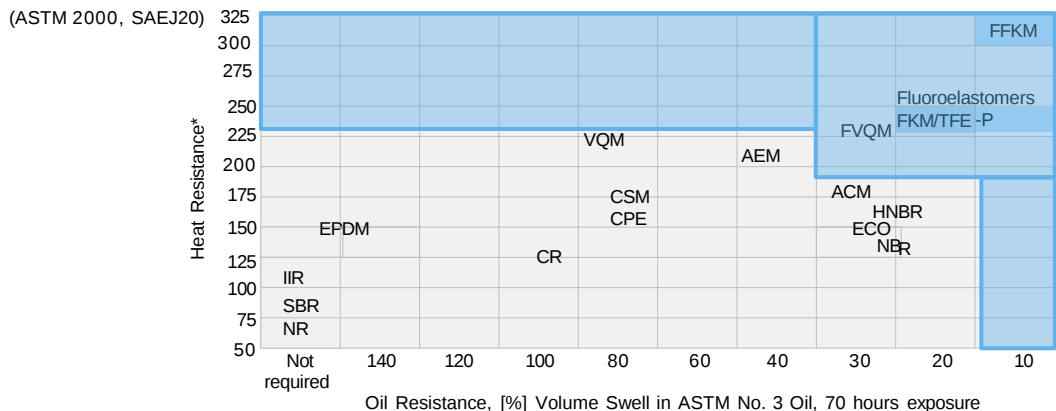


Figure 1: Elastomer families plastics rated against heat and oil resistance³

The ASTM swelling test for elastomers show that **in the domain of high temperature (>200°C)**, there is **no alternative for fluor elastomers**

However they often do not match all the properties of the original substance, making them less desirable (2/3)

Other polymers: focus on Thermoplastics

Overview of Chemical Resistance of Resins to Chemicals at 20 °C

		PFAS				Alternatives						
		ETFE	FEP/TFE/ PFA	FLPE	FLPP	HDPE	LDPE	PC	PETG	PP	PVC	TPE**
E	30 Days of constant exposure causes no damage. Plastic may tolerate for years	E	E	E	E	E	E	E	G	E	E	G
G	Little or no damage after 30 days of constant exposure to the reagent	E	E	G	G	G	G	G	N	G	G	F
		E	E	E	E	E	E	G	G	E	G	E
		E	E	G	G	G	G	G	G	G	G	G
F	Some effect after 7 days to reagent. The effect may be crazing, cracking, loss of strength or discoloration	E	E	F	E	E	E	N	N	E	E	F
		G	E	G	G	G	G	N	G	G	N	N
		E	E	E	G	G	F	G	G	G	G	E
N	Not recommended. Immediate damage may occur. Depending on the plastic, the effect may be severe crazing, cracking, loss of strength, discoloration deformation, dissolution or permeation loss	G	E	E	N	N	N	N	N	N	N	N
		G	E	G	F	N	N	N	N	N	N	F
		G	E	G	G	N	N	N	N	N	F	N
		E	E	F	F	F	F	F	F	F	G	N

For thermoplastics, PFAS alternatives cannot offer the required broad chemical resistance combination for all industrial applications

However they often do not match all the properties of the original substance, making them less desirable (3/3)

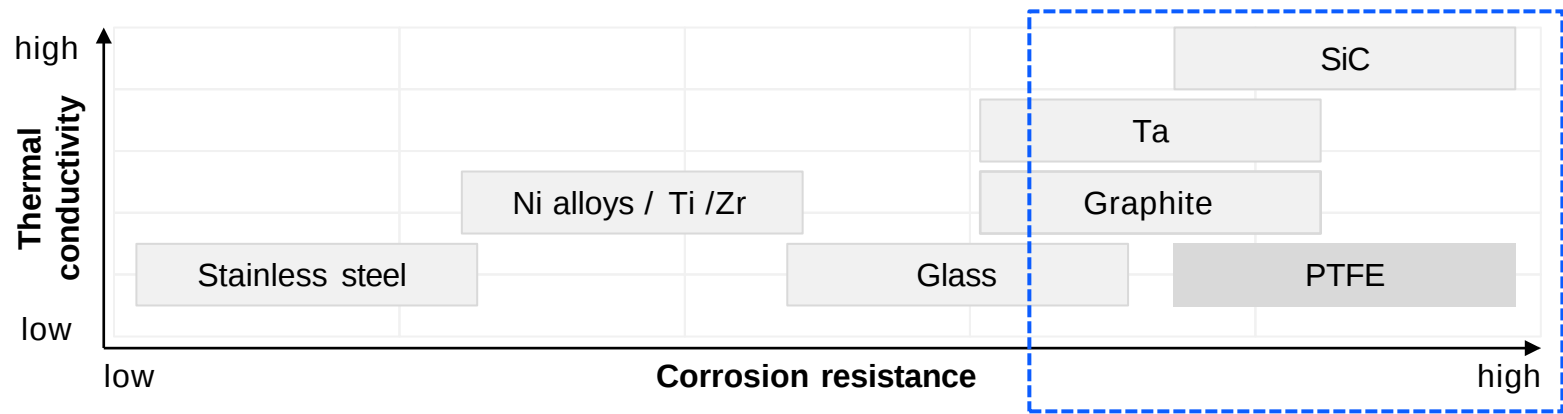
Focus on Metals & Glass

Comparing the properties of metals and glass with fluoropolymers

Metals and glass offer lower levels of resistance in terms of chemical resistance and formability as fluoropolymers when compared

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)	Equivalent or worse (shape creation)
Glass	Equivalent	Worse	Worse	Worse

Metals and glass rated against corrosion resistance and thermal conductivity¹



- 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

Chemical companies have started identification of some alternatives to PFAS-based equipment

Alternatives* identified by chemical companies in workshops

Type of industrial	Equipment	PFAS	Alternative
Chlorine chemistry	#1 Common**	Piping Refrigerant gas	PTFE, PVA, PVDF No information
	#2	Considers that alternatives exist depending on the use case but did not identify specific alternatives	
	#3	Did not identify alternatives for the moment	
Petchems/Refinery	#4	Did not identify alternatives for the moment	
	#5 Common	Gaskets Valves - body Piping (tubes)	PCTFE PCTFE PFA
Specialized chemistry (incl. fine chemicals)	#6 Common	Gaskets	PTFE
		Refrigerant gas	R407, R410, R22
		Vessels	PVDF
	#7 Common	Gaskets	PTFE
		Piping	PTFE
		Vessels	PVDF, ECTFE
		Valves	PTFE, PFA, PVDF
	Specific	Heat Exchangers	PVDF, ECTFE
	#8 Common	Piping	PVDF
		Piping	PTFE
		Vessels	PDF
	Specific	Filters	PTFE
		Heat Exchangers	PTFE
	#9 Common	Piping	PVDF, PTFE
		Refrigerant gas	R22, R134a, R404 a, R407, r427a,
	#10 Common	Piping	PTFE
		Valves	PTFE
		Refrigerant gas	No information

*Alternatives have been identified only for certain use cases and limits to alternatives are presented in slide 34 and 35. **Common as common equipment to all the companies
Sources: Survey of Chemical players and suppliers

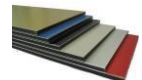
The industry has identified some potential substitutes for the following PFAS equipment for certain use cases (1/2)

PFAS and alternatives identified in gaskets and piping equipment*

Equipment	Illustration	PFAS	Alternative	Alternatives' limits
Gaskets		PCTFE, PTFE	Metallic (e.g., Nickel) gaskets	Compatibility issues with some gases (e.g. CO), very high cost, requires the replacement of all affected fittings
		PTFE	Graphite or Mica (silicate) gaskets	Possible contamination issues
			EPDM, NBR**	Lower Chemical resistance (less safety in chemical plants, higher emissions) ¹
			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 industry has identified some potential substitutes for the following PFAS equipment for certain use cases (2/2)

PFAS and alternatives identified in valves, refrigerant gas and coating*

Equipment	Illustration	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
		PTFE	Polyethylene	Lower upper temperature limit
Valves – Washers** (Intermediate components)				
Valves - Gaskets		FPM, FKM, Viton, PTFE	EPDM	Lower chemical resistance (less safety in chemical plants, higher emissions), not suitable for all application
Refrigerant gas		R-Gas	Ammonia	Higher risks due to toxicity, not suitable for chlorine processes, impact on refrigerant auxiliary system design and on energy consumption
			CO2	Much higher-pressure requirements than r-gas 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/Methane)	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: FergusonIndustrial, Alundong, BuyBestAc, Survey of Chemical players and suppliers, Desktop research, Accenture analysis

Although for some equipment, it's very challenging to find an alternative

Equipment

Membranes & diaphragms for Electrolysis

Illustration



PFAS

PFSA, PTFE (Nafion, Aquivion)

Why no alternatives

- Some alternatives banned in Europe (mercury, asbestos)
- There is no technical solution to date that can perform efficiently the filtration, the separation and the selectivity

Aside the material performance, the alternatives have other drawbacks that would make substitution challenging

Safety of the future installations

- As they are not widespread use material, need to demonstrate performance in the long term of existing alternatives. Some known reduced performances: sealing performance, emission
- International design standards for PFAS based equipment well established in the industry

Alternatives development

- Process potentially lasting many years, requiring:
 - R&D
 - Testing
 - Approval from certifying bodies and clients
- Long guarantee of new products required by clients (typically around 10 years)

Production asset and supply chain adaptation

- Production asset debottlenecking:
 - New sites to be build 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 in procuring potential alternative material (e.g., tantalum)

Properties of alternative materials

- To satisfy the desired properties for equipment the alternative materials to PFAS will also be persistent materials, which will could bring similar challenges to PFAS long life

PFAS presence in alternative materials / equipment

- PFAS potential used to improve performance of alternatives:
 - Some alternatives coated with thin layer of PFAS
 - PFAS surfactants used in the production of non-PFAS polymers identified as theoretical substitutes to PFAS polymers

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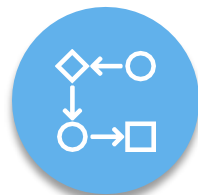
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Chemical and refining companies identify 4 sets of challenges associated with a ban of PFAS use in industrial equipment

Summary of challenges identified by chemical companies



No known alternatives to date for some equipment and unfavorable performance of already identified materials



Insufficient supply chain maturity with little to no capacity for alternatives identified



Substantial impact on indirect costs (maintenance) and impact on utilization (more frequent failure / maintenance activities)



High CAPEX required to transform plants linked to use of PFAS in core equipment and severe commercial impact linked to interruption of production

Workshops with the chemical companies allowed to identify potential improvement of PFAS management in plants

Potential improvement of PFAS management

1 Traceability of PFAS in Equipment

- Attributes like *type, quantity, origin, ...* of PFAS needs to be identified in each chemical equipment (e.g., material passport)
- Manufacturers of PFAS containing equipment to be made accountable



2 More stringent control of PFAS degradation and end-of-life management

- Chemical and refining companies to enforce more stringent control of PFAS degradations (e.g., monitoring of potential degradation of PFAS materials, measurement of traces in end products and waste waters, ...)
- Potential more stringent segregation of PFAS-containing equipment at end-of-life by industrials
- Communication with regulators and the public to be reinforced



3 Collaboration between suppliers and chemical companies

- Chemical companies to jointly work with equipment and material suppliers to accelerate development of alternatives
- Need to provide more specific requirement for chemical plant operations and to test new products from suppliers

