Study on uses of PFAS in chemical manufacturing plant equipment

Final Report

August 2025

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Executive Summary (1/5)

Introduction

- **The Per- and polyfluoroalkyl substances (PFAS) are a broad group of synthetic chemicals**, estimated between 4,000 to 15,000 **distinct PFAS compounds**. These substances, characterized by their carbon-fluorine bonds, exist in solid, liquid, or gaseous forms and are widely used across various industries

- Our study focuses specifically on PFAS used in chemical manufacturing equipment and does not address PFAS production or applications outside of chemical manufacturing. The three key objectives are: **(1) quantifying PFAS usage in industrial equipment, (2) evaluating potential substitution options, and (3) assessing the economic impact of potential restrictions on production and use of PFAS-containing components**

- This study is based **on a survey covering 470 plants across Europe, more than 30 one-on-one interviews** with experts, industry associations and equipment suppliers**, along with desk research.** It builds on **Accenture's previous 2023 qualitative study -** *The Use of PFAS in Chemical Plant Equipment*.

Estimation of PFAS inventory in EU chemical manufacturing plants

- Across equipment in chemical manufacturing plants, **PFAS are primarily found in two categories: fluoropolymers and F-gases**
- **The PFAS inventory** across equipment in chemical manufacturing plants in Europe — primarily fluoropolymers — is estimated to be **between 23 and 39 kt,** which represents on average 2 to 3 tons in each of the 13 000 chemical plants in Europe
- **Fluoropolymers are valued in equipment for their strong combination of properties**, including chemical and temperature resistance, and mechanical strength. They are critical in applications such as gaskets, valves and linings
- **The fluoropolymer inventory** across all markets is estimated to be between **19 and 35 kt**, while their **annual use is estimated at 2 to 4 kt**. **Annual global fluoropolymer use is estimated to be around 450 kt in all industries**, with Europe accounting for about 20% of global use
- **F-gases are used in refrigeration systems**, industrial chillers, and high-temperature heat pumps for waste recovery
- **The F-gases inventory** across all markets is estimated to be **4 kt**, while their **annual use is estimated at 0.4 kt.**
- The elements containing fluoropolymers and F-gases in chemical manufacturing plants are estimated, based under normal operating conditions, to be **replaced in 10 years** on average. However, replacement cycles vary by elements type: gaskets are typically replaced within 7 years, valves within 8 years, and piping lasts an average of 12 years

Executive Summary (2/5)

Focus on fluoropolymers

- While each European chemical manufacturing site varies in its use of fluoropolymers, **PTFE is the most used fluoropolymer, making up, on average, 73% by weight of all PFAS in a chemical manufacturing plant. Fluoropolymer-containing pipes, valves, and gaskets are the main components containing fluoropolymers,** with piping accounting for 45%, valves 26%, and gaskets about 25%. Expansion joints and O-rings represent respectively 2% and 1 % share. We estimated that on average 20,000 elements (excluding piping) contain PFAS in a chemical manufacturing plant in Europe
- While **fluoropolymer-containing pipes represent only 2% of the total piping (21 km of total piping on average)** in a plant, they **account for on average half share of fluoropolymer weight in a plant.** They are either fluoropolymer-lined pipes and pipes made entirely of fluoropolymer
- **Valves, on average 1,800 per plant, can contain multiple types of fluoropolymers**, with PTFE being the most common one. **Check valves are commonly used and represent nearly half of the share of fluoropolymer weight in valves**, due to their critical role in process safety as passive devices to prevent backflow
- Although **each gasket contains only a small amount of fluoropolymers, the high numbers of gaskets in a plant,** typically 14,000, makes them **significant contributors to total fluoropolymer use**, with PTFE being the most commonly used material
- **While expansion joints use a significant amount of fluoropolymers**, primarily PTFE, to absorb thermal expansion, vibration, and mechanical movement—protecting piping systems and equipment from stress and damage - **their relatively low quantity (200 on average by plant) makes them a marginal contributor** compared to other elements
- **In O-rings (4,300 on average by plant), the use of fluoropolymers is more varied, with FKM, PFA, and PTFE** being the most predominant PFAS

Executive Summary (3/5)

Status of alternatives

- **Substituting fluoropolymers presents significant challenges**, as alternative materials often fail to meet their unique **combination of properties**: temperature resistance, chemical resistance, and mechanical resistance. While individual alternatives can match specific characteristics, none provide a comprehensive replacement. As a result, **the chemical manufacturing industry relies on fluoropolymers out of necessity for specific uses to ensure operational safety.**
- **3 categories of materials compete with fluoropolymers in diverging conditions :**
  - **Nickel alloy, Hastelloy (metals), ceramics and graphite (other materials)** offer stability across broad **temperature range**, though most of other alternatives perform less effectively under **cryogenic conditions**
  - **Nickel alloy, Hastelloy (metals) and glass (other materials)** match most of fluoropolymers' **chemical compatibility**, while other alternatives offer partial resistance but lack full-spectrum compatibility
  - **High-performance plastics** (PP, PET, HDPE, PEEK), provide good **mechanical properties**, matching the fluoropolymers durability, robustness, elasticity, and wear resistance but to a large extent do not offer the same thermal resistance
- **In a chemical industry environment with very high HSE standards and sensitive industrial processes, reassessment based on specific needs and operating conditions will be necessary** to evaluate possible alternatives on a **case-by-case basis**
- **Retrofitting existing plants to comply with new regulatory constraints** will be a major challenge as fluoropolymers are used in the core industrial equipment (e.g., reactor, piping), requiring, if feasible, lengthy shutdowns of plant beyond typical turnarounds
- **The substitution will be more feasible for new-build plants**, as their design can incorporate alternative solutions from the outset

Executive Summary (4/5)

Economic impact of pending Universal PFAS restriction under REACH

- **The chemical manufacturing sector is characterized by capital intensity, inflexible production assets, and long investment cycles.** Uncertainty is a critical challenge, as significant investments are required for future changes, making **clarity essential to ensure informed decision-making and effective allocation of resources**
- **Any new regulation is expected to have both economic and socio-economic impacts on chemical manufacturing companies. The Universal PFAS restriction proposal' impacts were assessed using three possible scenarios:**
  - **Scenario 1: Restriction on PFAS takes place in 2029** after which it is impossible to obtain new equipment containing PFAS materials, but equipment already in use and in stock in European chemical manufacturing plants can be used until replacements are needed
  - **Scenario 2: Restriction takes place in 2041 instead**, while the rest of the parameters remain identical to first scenario
  - **Scenario 3: Derogation without time-limit** is granted, under the condition that a **detailed substitution and emission reduction plan is implemented as of 2029**
- **Scenario 1 and 2 (restriction taking place in 2029 and 2041 respectively)**
  - **In addition to potential operational safety issues with challenges to maintain operations (due to availability of substitutes beyond existing inventory of spares), most companies declare they would face severe consequences** (e.g., Turnover, operational costs, CAPEX, employment) if PFAS uses were restricted for new equipment or components within the next 5 to 15 years (scenario 1 and 2). **The lack of suitable alternatives would significantly disrupt their operations, with an expected increase of more than 50% from current OPEX baseline**
  - **Transitioning away from PFAS remains a major challenge, requiring a broad transformation of the industry**. This includes the **development of alternative substances**, supported by R&D, testing, and regulatory approvals, while ensuring these alternatives are cost-competitive. It also involves **investing in production capacities for potential new materials to meet growing demand**, addressing health, safety, and environmental (HSE) concerns for future installations
  - **Restrictions** (scenario 1 and 2) **would impact not only companies themselves, but also the entire value chain,** including both upstream suppliers (feedstock, raw materials) and downstream clients

Executive Summary (5/5)

- **Specifically for scenario 2 (restriction taking place in 2041)**
  - **Even if viable alternatives emerge before 2041 (scenario 2)**, **chemical manufacturing companies anticipate an increase in operating costs** (55% increase from current baseline)**,** primarily due to the lower efficiency of these alternatives, which leads to increased maintenance and downtime**. This factor could push some companies to relocate in search of more competitive conditions**. However, relocation is not an option for all, as some rely on locally sourced feedstock, making plant closures a possible outcome
  - While not all European chemical plants would be affected equally, **chemical manufacturing companies believe that an extended deadline (scenario 2) offers little to no relief for equipment reliant on PFAS**, as uncertainty around suitable alternatives remains a major challenge and no clear path to substitution currently exists. The impact remains similar in terms of key business metrics, operating and capital costs impacts
- **For scenario 3 (no time limit, substitution and emission reduction plan as of 2029)**
  - **A time-unlimited derogation (Scenario 3), contingent on the implementation of a PFAS substitution and emission reduction plan starting in 2029, would enable most companies to continue operations**, although the impact may vary across businesses. Chemical manufacturers anticipate fewer disruptions to the value chain (affecting less than 50%) and estimate a 30% increase in operating costs, primarily driven by PFAS management, emission reduction, and monitoring requirements
  - Current EU and industry objectives **prioritize industrial safety, necessitating the continued use of PFAS in the short term until suitable alternatives are identified, tested, and scaled for production**
  - Members **emphasize the importance of the global competitive landscape**, noting that additional regulatory costs could give an advantage to competitors outside the EU in an already challenging environment for the European chemical manufacturing industry linked to high energy prices , lack of feedstock advantage and highly demanding regulation
  - As a result, **businesses are evaluating all possible options**, including reducing or ceasing production, or relocating operations

Methodology (1/2)

PFAS inventory methodology

- **The total PFAS inventory (kt) in EU chemical manufacturing plants** is estimated for both **fluoropolymers and F-gases**
    - **The fluoropolymer inventory (kt)** is calculated by multiplying the annual use (kt/year) across equipment in EU chemical manufacturing plants by the average replacement cycle (in years) of components containing fluoropolymers within a plant
    - **The F-gas inventory (kt)** is calculated by multiplying the annual use (kt/year) of F-gases in EU chemical manufacturing plants by their average replacement cycle (in years) within a plant
- For each inventory, a **top-down approach** based on information collected from commercial databases, desk research, and expert interviews was thoroughly **cross-checked** with a **bottom-up approach** primarily derived from survey results to ensure **consistency**

PFAS alternatives methodology

- Due to the combined thermal, chemical, and mechanical properties of fluoropolymers, **each potential alternative was evaluated against each of these properties**:
    - **Thermal:** ability to withstand high and low temperatures without degrading, losing performance, or undergoing structural changes
    - **Chemical:** ability to resist corrosion, degradation, or reaction when exposed to aggressive chemicals (e.g., acids, bases, solvents, gases)
    - **Mechanical:** ability to endure mechanical stress, pressure, friction, and wear through strength, durability, and flexibility properties
- The potential alternatives evaluated include **polymers, metals and alloys, and other materials such as ceramics, glass, and graphite**, representing a total of **22 potential alternatives**
- The challenges of transitioning away from PFAS-free alternatives assessed through 4 dimensions based on expert interviews: **alternatives development, value chain adaptation, HSE concerns and retrofitting**
- **An additional assessment** focused on how potential PFAS restrictions would differently impact **existing plants and new investments**

Methodology (2/2)

PFAS economic impact methodology

- **A section of the survey, focused on the economic and socio-economic impacts of PFAS regulations on EU chemical manufacturing companies,** was developed and completed by Cefic members. It includes **three scenarios**:
  - **Scenario 1: The restriction on PFAS takes place in 2029** after which it is impossible to obtain new equipment containing PFAS materials, but equipment already in use and in stock in European chemical manufacturing plants can be used until replacements are needed
  - **Scenario 2: The restriction takes place in 2041** instead, while the rest of the parameters remain identical to the first scenario
  - **Scenario 3: A derogation without time-limit** is granted, under the condition that a **detailed substitution and emission reduction plan is implemented as of 2029**
- **The quantitative and qualitative answers** were collected and analysed by Accenture
- The main topics included in the survey are:
  - **Value chain impact** (affected value chain, upstream, downstream)
  - **Impact on key business metrics** (Portfolio, turnover, GVA)
  - **Impacts on operating costs** (OPEX, Maintenance, Downtime)
  - **Capital costs** (CAPEX, R&D)
  - **Socio-economic costs** related to impacts on direct and indirect employment (refers to jobs external to companies, such as subcontractors, suppliers, or local businesses close to the plant)
  - **Costs related to PFAS handling** (monitoring and reporting, emission reduction, PFAS management costs)

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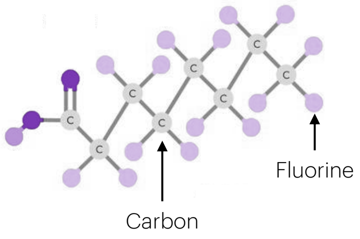
Context

Presentation of PFAS

C-F



- PFAS stands for **Per- and polyfluoroalkyl substances**
- “PFAS” does not refer to a specific molecule but a **group of molecules**
- PFAS contain at least **one fully fluorinated methyl** or **methylene carbon atom** (without any H/Cl/Br/I atom attached to it)*
- The strong carbon-fluorine bonds give PFAS **useful properties** but also make them potentially **environmentally persistent**

4,000 – 15,000

The exact number of PFAS is hard to determine due to their vast nature:

- The OECD** classifies **over 4,500 molecules** as PFAS
- The 2023 restriction proposal dossier submitted to ECHA estimates **around 10,000 PFAS substances**
- The US EPA*** identifies more than **14,000 different PFAS** compounds

Thanks to their combined properties, PFAS are used in many products across industries

Physical

- Water repellence
- Surface lubrication
- Friction

Non-stick cookware

Protective footwear

Mechanical

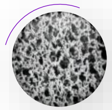
- Stress
- Strain
- Wear

Seals (O-rings, gaskets)

Bearings

Chemical

- Chemical inertness
- Insolubility
- Acid resistance

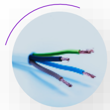


Filter-membranes

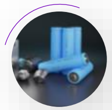
Containers

Thermal and electrical

- Heat insulation
- Thermal conduction
- Dielectric properties



Wire and cables



Batteries

Note: *New Definition of the OECD in 2021 ; **Organization for Economic Co-operation and Development; ***Environmental Protection Agency (US)
Source: OECD Database, Accenture research and analysis

Context

Possible restriction on PFAS

Proposal for a Universal restriction on PFAS under REACH

- In **January 2023**, the Competent Authorities of five States submitted to the European Chemicals Agency (ECHA) a **proposal for a Universal restriction on PFAS under REACH**
- In **March 2023**, **ECHA launched a consultation** on the proposal **open to all stakeholders**
- Since then, **ECHA's expert Committees have been reviewing the proposal** and the comments received. They **will formulate an opinion for the European Commission** on the proposal, accounting also for the comments received

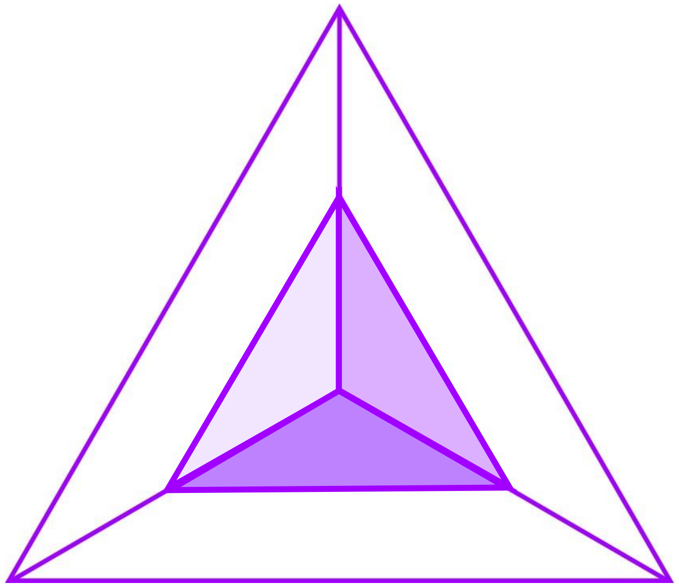
Cefic contributed to ECHA process

- **European chemical industry has, inter alia, investigated** PFAS uses in their plant equipment
- **Phase 1 study – *qualitative study* -** *The Use of PFAS in Chemical Plant Equipment* - mapping out **PFAS usage across** the chemical manufacturing industry was conducted by Cefic in collaboration with Accenture in 2023
- **Phase 2 study – *more quantitative study* -** *Study on Uses of PFAS in Chemical Manufacturing Plant Equipment* - launched to further **quantify PFAS usage, take stock of progress on alternatives,** and **assess economic impacts** based on three different scenarios of possible PFAS restrictions, was conducted by Cefic in collaboration with Accenture and constitutes the present study

Source: Cefic, Accenture research and analysis

Context

Purpose of the study



01 | QUANTIFICATION

The study aims to quantify the use of PFAS in industrial equipment within chemical manufacturing plants

02 | SUBSTITUTION

The study also intends to evaluate the current state of play regarding possible substitutions for these PFAS uses

03 | IMPACT EVALUATION

Additionally, the study assesses the potential economic impact of PFAS restrictions on equipment that contains these substances in the chemical manufacturing industry

Study focuses solely on **equipment in chemical manufacturing sector** and does not include the production of PFAS or their use in chemical reactions

The study aims to quantify usage of PFAS across industrial equipment in the chemical manufacturing sector, evaluate alternatives, and assess economic impact

Context

Study sources – Insights from previous qualitative 2023 study

1 **This study builds on insights from previous qualitative 2023 study**

Questions answered

- **Which PFAS are used** and in which type of equipment?
- **Why are PFAS used** in chemical plants?
- What are the **main alternatives** identified by study participants?
- What are the **challenges of these alternatives**?
- What would be the **timing to replace PFAS-containing equipment** with technical alternatives identified?
- What would be the **impact of the proposal** to restrict PFAS on the chemical industry as a PFAS equipment user?

Key Outcomes

PFAS usage by equipment type

- Mainly found in **seals, lining, and valves**, typically as **solid-form fluoropolymers**
- Used for **performance and workplace safety reasons**, valued for unique combination of chemical, thermal and mechanical resistance, often **without full transparency on material composition**

PFAS substitution

- **Lack of viable alternatives** for certain equipment (e.g. membranes) due to PFAS's unmatched combination of properties
- Long timelines and industry constraints — R&D and testing for supply chain readiness—make full **replacement a 10+ year challenge**

PFAS impact on chemical manufacturing industry

- Severe operational and financial risks under PFAS restrictions, including **2–3x higher maintenance costs**, plant shutdowns, and **rebuilding 20–50% of assets**
- PFAS bans could lead to **halted production** or **relocation of future investments**

Context

Study sources – Primary and Secondary Research

2 **Primary research was used to collect first-hand insights from industry stakeholders and validate industry practices**

Survey development & results analysis

- Development of **300+ question survey** to investigate PFAS uses, **covering PFAS elements and equipment**, and **optimised with Cefic members**
- Analysis of survey **responses covering 470 plants of Cefic members** and representing the diverse European chemical manufacturing industry landscape

Expert interviews

31 interviews conducted with experts, industries associations and equipment suppliers

Internal tool for PFAS weight calculations

Creation of internal tool to **calculate the PFAS weight of components** in chemical manufacturing industry's equipment

3 **Secondary research supported and guided the primary findings by providing contextual knowledge**

Literature research

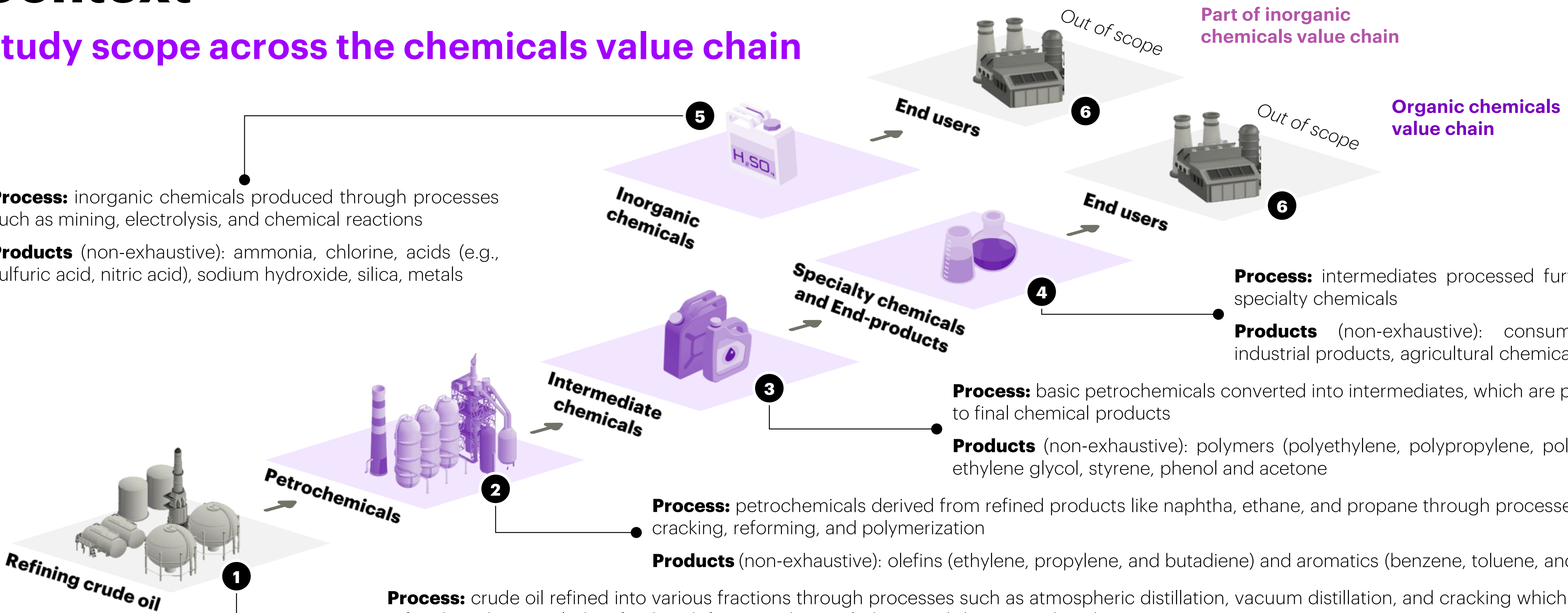
Use of advanced analytics for literature research:

- Technical data sheets
- Supplier websites
- News feeds
- Broker and market reports

All figures in the report are indicative estimates and should be interpreted as approximate values

Context

Study scope across the chemicals value chain



Process: inorganic chemicals produced through processes such as mining, electrolysis, and chemical reactions

Products (non-exhaustive): ammonia, chlorine, acids (e.g., sulfuric acid, nitric acid), sodium hydroxide, silica, metals

Process: intermediates processed further into specialty chemicals

Products (non-exhaustive): consumer and industrial products, agricultural chemicals

Process: basic petrochemicals converted into intermediates, which are precursors to final chemical products

Products (non-exhaustive): polymers (polyethylene, polypropylene, polystyrene), ethylene glycol, styrene, phenol and acetone

Process: petrochemicals derived from refined products like naphtha, ethane, and propane through processes such as cracking, reforming, and polymerization

Products (non-exhaustive): olefins (ethylene, propylene, and butadiene) and aromatics (benzene, toluene, and xylene)

Process: crude oil refined into various fractions through processes such as atmospheric distillation, vacuum distillation, and cracking which produce refined products, including feedstock for petrochemicals (e.g., naphtha, LPG, ethane)

Products (non-exhaustive): light gases (methane, ethane), liquefied petroleum gases (LPG: propane, butane), naphtha (a possible feedstock for petrochemicals), middle distillates (diesel, kerosene), fuel oils and asphalt

Legend: Scope of the study | Out of scope

Study covers vast majority of the chemical manufacturing industry

Context

Targeted PFAS scope

Main PFAS used in industrial equipment

Fluoropolymers

F-gases

Firefighting foams

Currently under discussion for specific regulations

Legend: Scope of the study | Out of scope

- **The previous qualitative study** identified that **3 groups of PFAS** are mostly used in industrial equipment within chemical industry: **fluoropolymers**, **fluorinated gases (F-gases)** and **firefighting foams,** representing around **50 PFAS**
- This study only focuses on **fluoropolymers** and **F-gases** as firefighting foams are covered by a separate restriction
- Fluoropolymers are **the main category of PFAS found in chemical plant equipment** as they display a unique set of **combined properties** (chemical resistance, thermal resistance, mechanical properties)
- F-gases are primarily used as **refrigerants**, propellants and in electrical insulation

Only about 50 of the thousands of identified PFAS are widely used in chemical manufacturing equipment—mainly fluoropolymers and F-gases, which will be the focus of our study

Context

Fluoropolymers & F-gases across industrial equipment in chemical manufacturing plants

Fluoropolymers are present in various **industrial elements** that are **located** within the **equipment** or **connect** different pieces of equipment together

Elements

Components


Gaskets


O-rings

Connectors


Piping


Expansion joints


Valves

Other products


Lining


Lubricants (incl. greases)

Equipment

Vessels


Columns (incl. column packing*)


Crystallizers


Drums


Dryers


Evaporators


Fired heaters


Heat exchangers


Mechanical separators


Reactors

Other equipment


Agitators


Compressors


Conveyors


Turbines /Fans


Crushers & grinders


Instruments


Membranes


Pumps (incl. motors and couplings)


Cooling towers


Refrigeration systems (incl. refrigerants & F-gases)

F-gases are mostly present in **refrigerants** and **cooling towers**

Fluoropolymers are widely used in equipment and connecting elements to equipment throughout most chemical plants while F-gases are primarily present in cooling towers and refrigeration systems

Note: *Structured and random packing
Source: Accenture research, interviews and analysis

Context

Key study challenges

PFAS value chain for industrial equipment

Raw materials & intermediates	*Fluorspar, hydrofluoric acid*
PFAS production	*Manufacturing of raw PFAS chemicals (e.g., fluoropolymers)*
Material & Formulation	*PFAS integrated lubricants, gaskets, membranes, …*
Components & Parts	*Treated parts such as gaskets, O-rings, …*
Industrial equipment	*Machines, reactors, pipes, pumps, valves using PFAS-treated components*

- The use of **PFAS embedded within materials and equipment**, rather than as direct substances, **complicates traceability** and makes **substitution more difficult**
- Identifying **where** and **how PFAS are used in industrial equipment is challenging**, as they are often **integrated into components** like gaskets, O-rings, valves, piping
- **The lack of comprehensive data on PFAS flows across the value chain** makes it difficult to assess their **presence** and potential **impact** on compliance and substitution efforts

PFAS value chain in industrial equipment is complex, making documentation and traceability difficult

Source: Accenture research, interviews and analysis

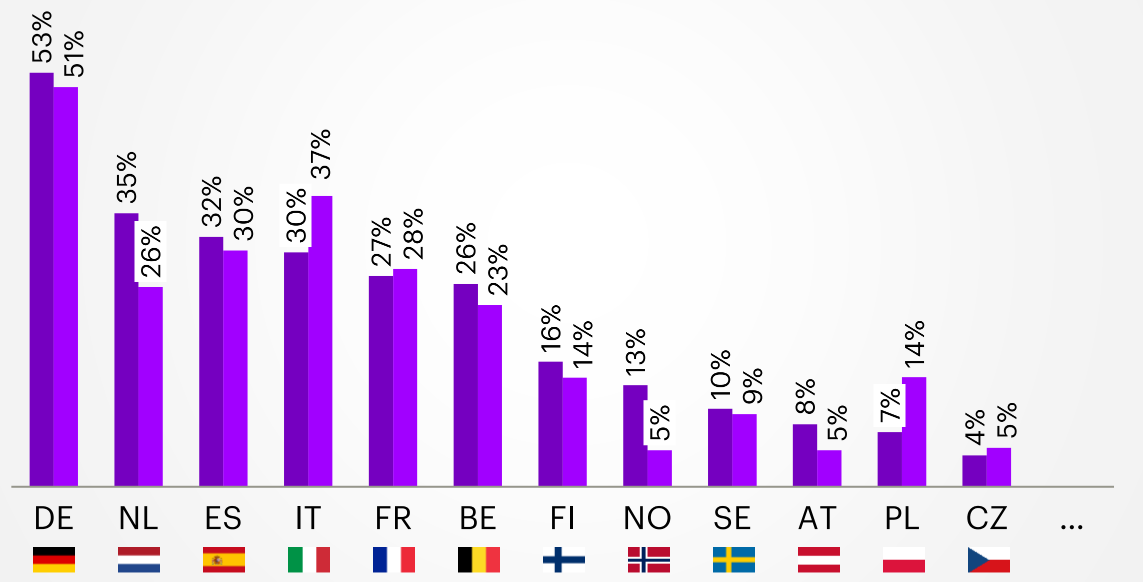
Context

Survey scope

- Over **1400 plants in 26 countries** were included in the previous qualitative study while this qualitative study covers more than **400 plants in 19 countries** due to the challenges involved with collecting **quantitative information about PFAS** in equipment and the survey's thoroughness which required an important time investment

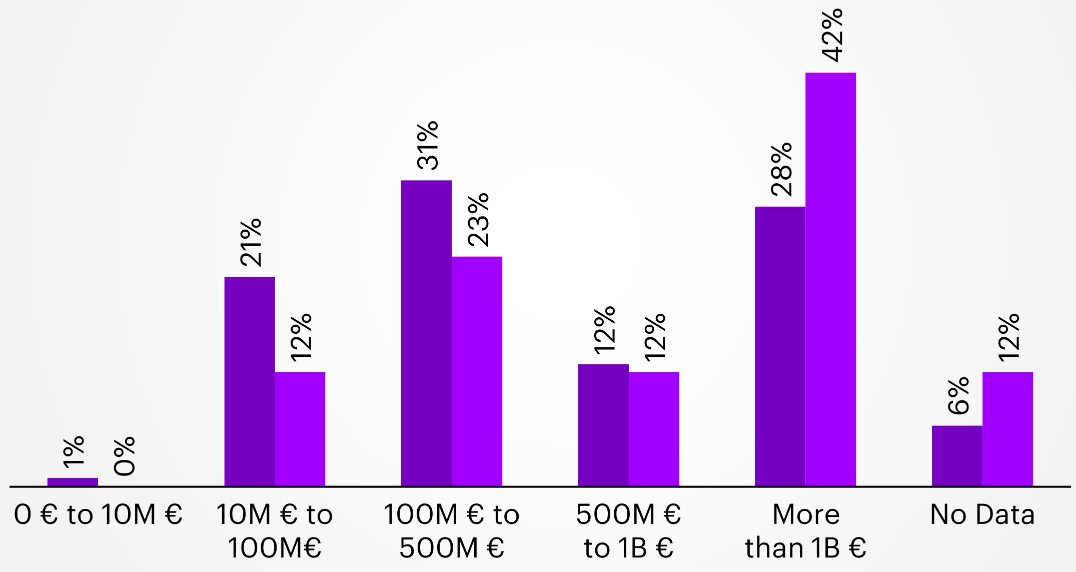
Respondents' geographic distribution

% of respondents having plants in a specific country



Respondents' turnover distribution

% of respondents by turnover of companies covered



The survey designed for this study analysed 400 plants across 19 countries, with respondent distribution by EU region and turnover brackets ensuring representative results

Source: Accenture research, interviews and analysis

Legend: Qualitative study (2023) | Quantitative study (2025)

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PFAS Inventory

Executive Summary (1/3)

PFAS inventory methodology

- **The total PFAS inventory (kt) in EU chemical manufacturing plants is estimated by combining the fluoropolymer inventory and the F-gases inventory**
  - **The fluoropolymer inventory (kt)** is calculated by multiplying **the annual use*** (kt/year) across equipment in EU chemical manufacturing plants **by the average replacement cycle** (in years) of components containing fluoropolymers within a plant
  - **The F-gases inventory (kt)** is calculated by multiplying **the annual use*** (kt/year) of F-gases in EU chemical manufacturing plants by **their average replacement cycle** (in years) within a plant
- For each inventory, a **top-down approach** based on information collected from commercial databases, desk research, and expert interviews was thoroughly **cross-checked** with a **bottom-up approach** primarily derived from survey results to ensure **consistency**

Fluoropolymer inventory methodology

- **The annual use* of fluoropolymers**, derived through a top-down approach, is calculated starting from global fluoropolymers use and narrowing across equipment in European chemical manufacturing plants via **two methodologies**:
  - **CAPEX-based**: the analysis is based on share of CAPEX investment between chemical manufacturing and industrial processing sectors, and CAPEX ratio comparison between European and global chemical manufacturing industries
  - **Seals as a proxy:** the analysis focus on seals, a common fluoropolymer-containing component, that are used as a proxy to estimate annual fluoropolymer use in EU chemical manufacturing industry
- **The average replacement cycle** was assessed using elements' average replacement cycles (in years) weighted by their share in total fluoropolymers weight
- **Some detailed insights** were collected using **bottom-up approach: most commonly-used fluoropolymers, weight share of fluoropolymers across main elements** (gaskets, O-rings, valves, piping and expansion joints), and **distribution of fluoropolymers within each component**

F-gas inventory methodology

- **The annual use *of F-gases,** derived through a top-down approach, is calculated starting from European F-gases annual use and narrowing to European chemical manufacturing plants
- **The average replacement cycle** is assessed using estimated annual losses
- **Some detailed insights** were collected using **bottom-up approach** for **F-gases by type** on average in a plant

Note: *Refers to PFAS that is added or replaced in equipment over the course of a year

PFAS Inventory

Executive Summary (2/3)

PFAS inventory results

- Across equipment in chemical manufacturing plants, **PFAS are primarily found in two categories: fluoropolymers** and **F-gases**. Total PFAS inventory currently in use or in stock across equipment in EU chemical manufacturing plants is estimated at **23 to 39 kt, corresponding to 1.8 to 3.0 t per plant**
- **Fluoropolymers** are valued in equipment for their **combined properties**, including chemical and temperature resistance, and mechanical strength. They are critical for operational safety in applications such as gaskets, valves and linings.
- **F-gases** are used in **refrigeration systems**, industrial chillers, and high-temperature heat pumps

Fluoropolymers inventory results

- The fluoropolymer inventory is estimated at **19 to 35 kt**, while **annual use is estimated at 2 to 4 kt**. On average, each of the estimated 20,000 elements containing fluoropolymers in a plant contains **approximately 150 grams of fluoropolymers**
- **The replacement cycle** under standard operating conditions is **expected to take around 10 years**
- **The PTFE is the most widely used fluoropolymer**, representing, on average, 73% of total fluoropolymer mass across equipment in EU chemical manufacturing plants

Fluoropolymers inventory across equipment results

- Most of the fluoropolymer usage by weight is **concentrated in piping (45%), valves (26%), and gaskets (25%)**. The expansion joints, O-rings, and other components represent less than 4%.
  - Various types of pipes exist, but this study focus exclusively on those containing fluoropolymers: fluoropolymer-lined pipes and pipes made entirely of fluoropolymer. **Fluoropolymer-containing pipes make up only about 2% of total piping** (21 km of total piping on average) in a plant but **remain the main source of fluoropolymers by weight**. PTFE is the predominant fluoropolymer used in fluoropolymer-lined pipes. Full-fluoropolymer pipes are primarily composed of PVDF, PTFE and PFA
  - **Valves, typically 1,800 per plant, can contain multiple types of fluoropolymers**, with PTFE being the most common one. From the 6 types of valves, check valves represent almost half of the fluoropolymer weight, followed by butterfly, gate and diaphragm valves each at around 15%
  - Although **each gasket contains only a small amount of fluoropolymer, their high numbers in a plant,** typically 14,000, makes them **significant contributors to total fluoropolymer usage.** PTFE is the most used fluoropolymer for gaskets, making up about 90% of their weight in a plant

PFAS Inventory

Executive Summary (3/3)

F-gases inventory results

- **The annual use of F-gases** in EU chemical manufacturing **represents a smaller share (less than 1%) compared to overall European annual use of 70 kt**
- **F-gases used in chemical plant equipment**—mainly in chillers and high-temperature heat pumps—are estimated at around **4 kt in total, with annual use near 0.4 kt**
- **The replacement cycle** under normal conditions is estimated to take on average **10 years**
- **R-407c accounts for 1/5th of all F-gases on average in a plant**, explained by its good performance and ability to be retrofitted into existing R-22 systems

PFAS inventory

Methodology

Fluoropolymer inventory (kt)
in use and in stock across the equipment in the EU chemical manufacturing plants

\+

F-gases inventory (kt)
in use in the EU chemical manufacturing plants

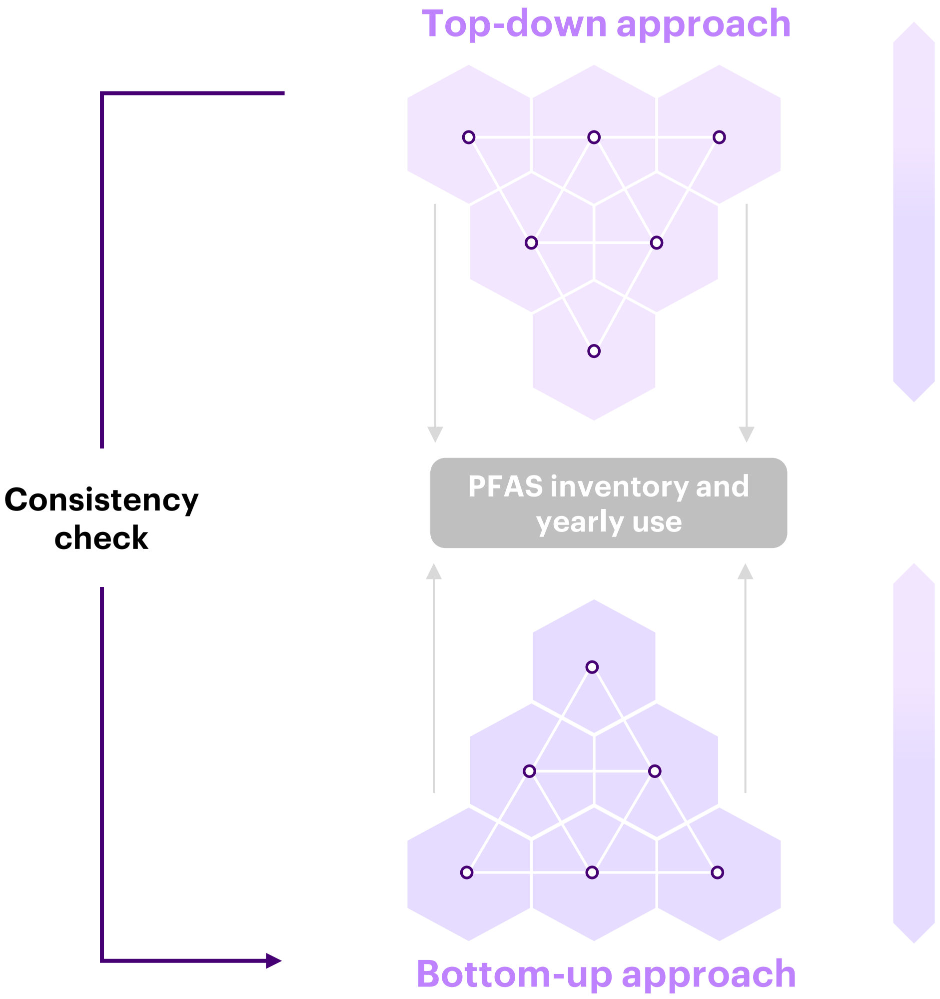
=

Total PFAS Inventory (kt)
total fluoropolymers and F-gases in use and in stock across the equipment in the EU chemical manufacturing plants

Based on **top-down** and **bottom-up** approaches

PFAS inventory

Top – down and bottom-up approaches



- The **overall quantity of PFAS use per year across all sectors** is estimated
- To **approximate annual use in EU chemical manufacturing plants**, the analysis considers the EU chemical manufacturing industry's share of global capital expenditures (CAPEX)
- The data is sourced from **commercial databases, desk research, and expert interviews**

- The survey response covering 470 plants of Cefic members seeks to understand with an as **high as possible level of granularity** the **presence and type of PFAS** across equipment in EU chemical manufacturing plants (PFAS weight, number of equipment,…)
- The survey also analyzes **the average replacement cycle of equipment**, to estimate the annual use of PFAS in the EU chemical manufacturing industry
- The insights are primarily sourced from **survey results**

Fluoropolymer inventory

Methodology

The fluoropolymer inventory is calculated by multiplying the **annual use** by the **average replacement cycle** of elements containing fluoropolymers in the EU chemical manufacturing plants

Annual use (kt per year)
of fluoropolymer across equipment in the EU chemical manufacturing plants

×

Average replacement cycle (years)
of elements containing fluoropolymer in a plant

=

Fluoropolymer Inventory (kt)
in use and in stock across equipment of the EU chemical manufacturing industry

Based on **Top-down approach** through **CAPEX** and **gasket** (proxy) methodologies

FOCUS ON FOLLOWING SLIDES

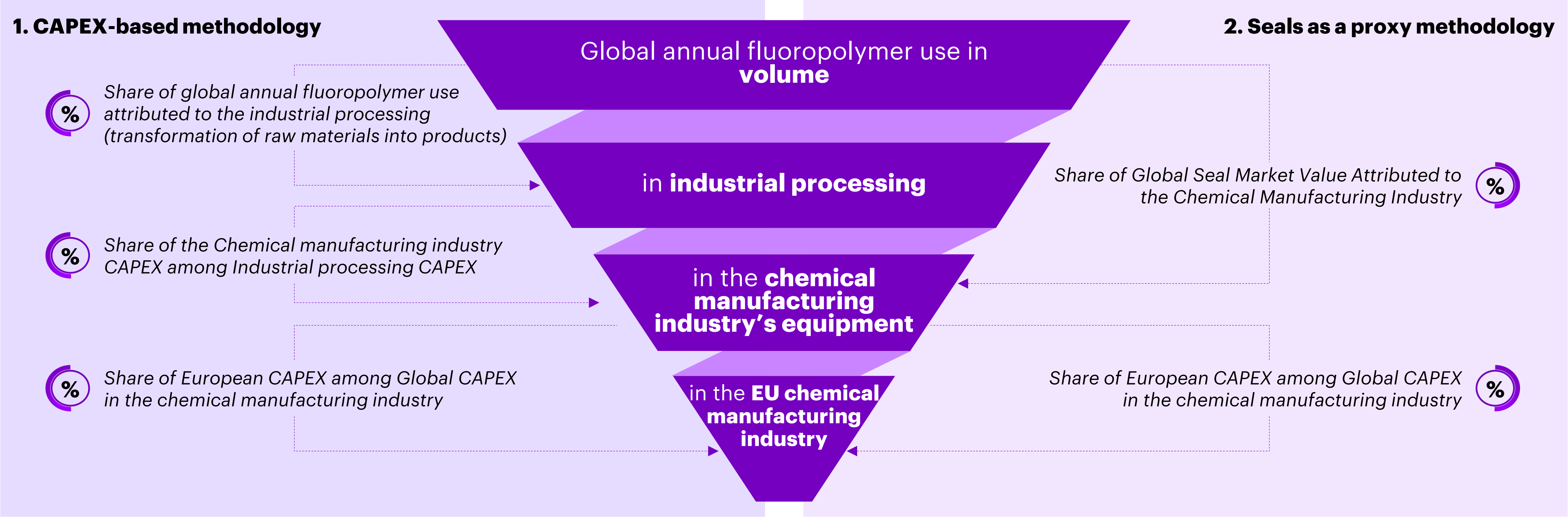
Based on **survey answers** and **expert estimations**

Fluoropolymer inventory

Annual use – Methodology

To estimate annual fluoropolymer use across equipment in the EU chemical manufacturing plants, we applied **2 distinct top-down methodologies:**

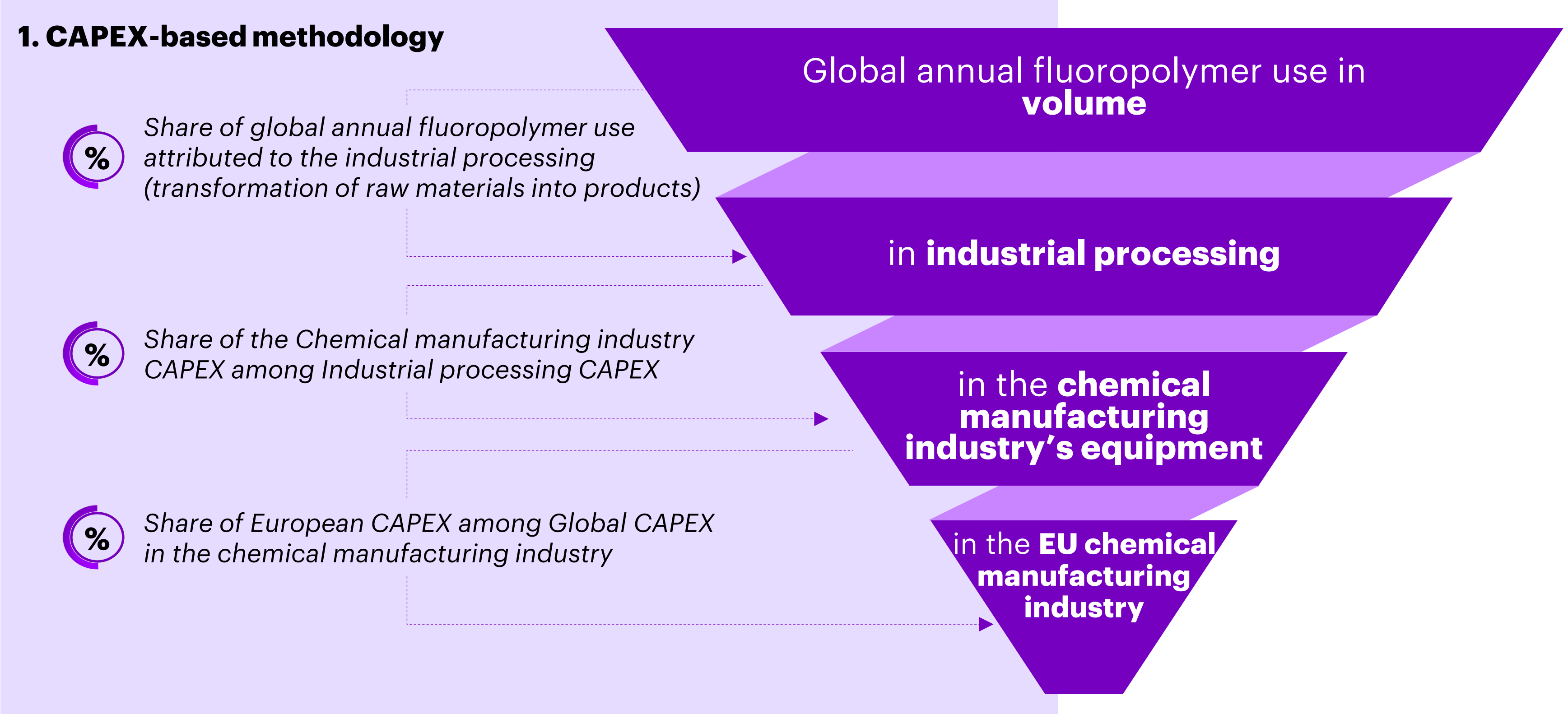
- **CAPEX-Based approach** for the **primary estimate**
- **A seals-based proxy approach** to **validate and reinforce estimate reliability**. The choice of seals as a proxy is justified by their widespread presence across the equipment of chemical manufacturing plants, and the availability of extensive global data



Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Annual use – CAPEX-based methodology

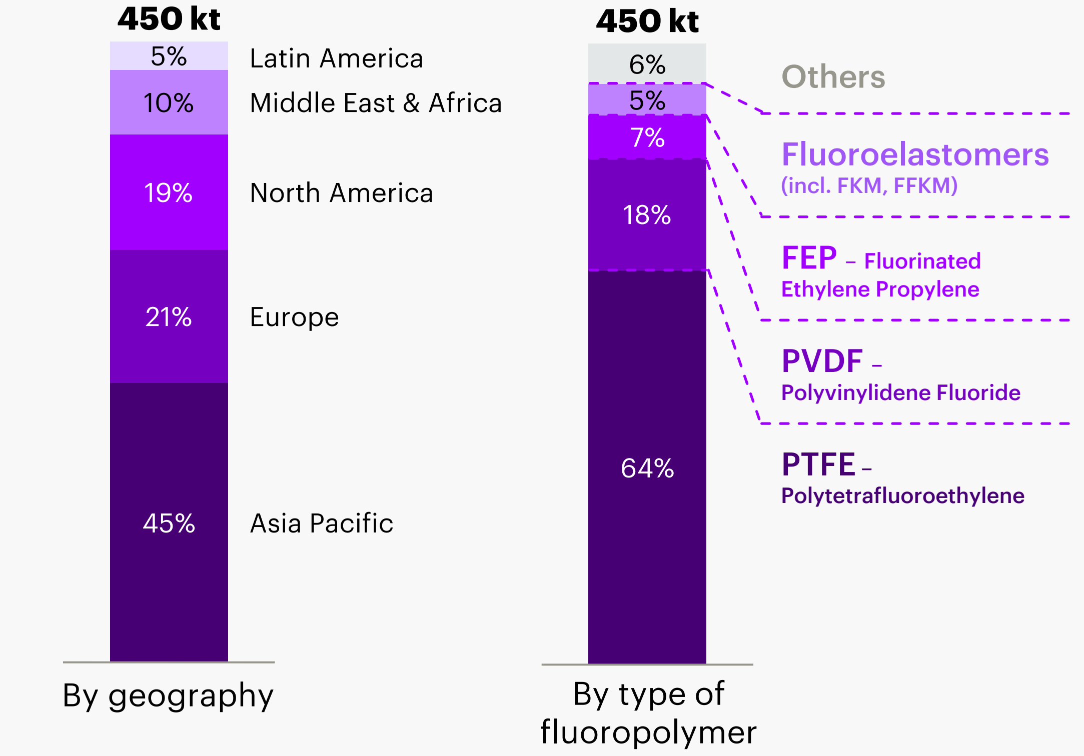


Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Annual use – Annual global fluoropolymer use

Annual global fluoropolymer use by geography and by type
(2022)
kt



- According to data from commercial market databases, **the annual global fluoropolymer use market** is estimated to represent a **volume of approximately 450 kt**
- Within this global market, **Europe ranks as the second-largest regional consumer**, accounting for around **21%** of total worldwide use
- Among the various types of fluoropolymers, **polytetrafluoroethylene (PTFE) stands out as the most widely used**, representing over **60%** of the total market volume

"… I confirm that the annual global use market of fluoropolymers exceeds 400 kt, with PTFE being the most widely consumed fluoropolymer …"

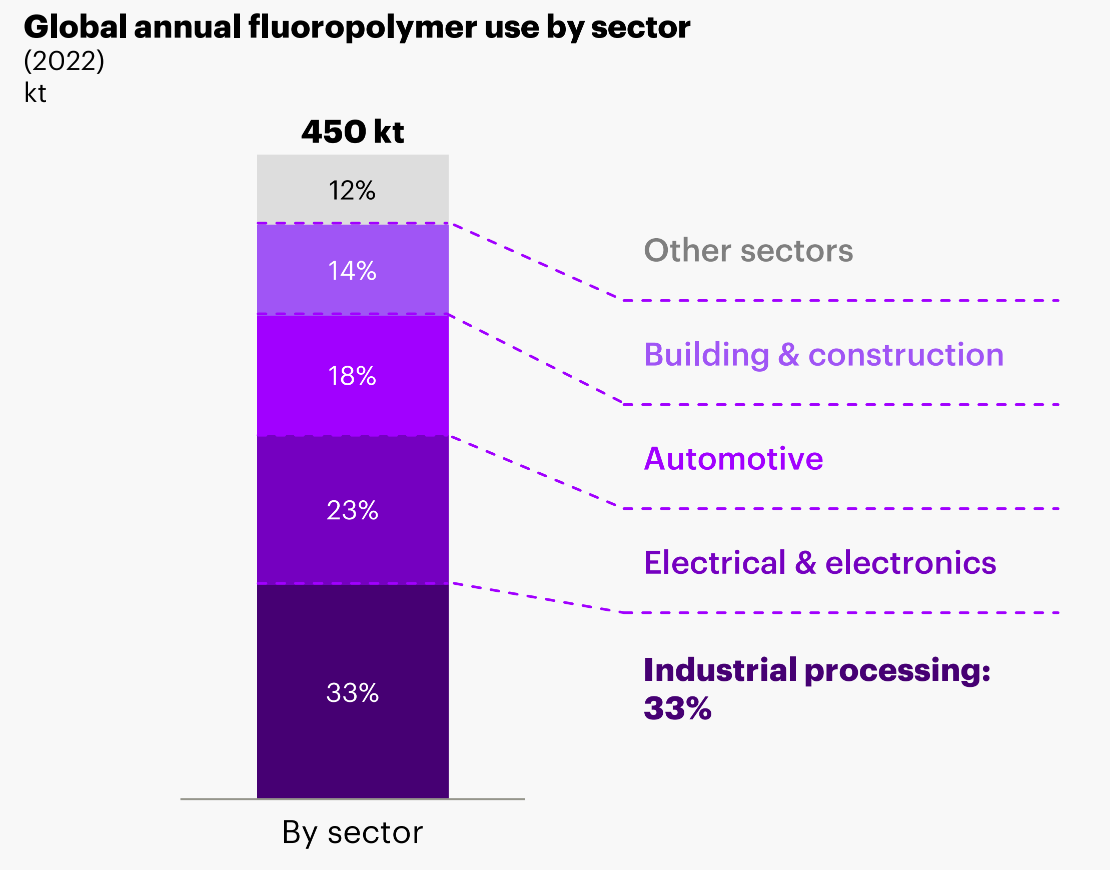
PFAS production expert

The global fluoropolymers annual use market is estimated at 450 kt

Source: BCC, Grand View Research, Accenture research, interviews and analysis

Fluoropolymer inventory

Annual use – Share of industrial processing (incl. chemical manufacturing industry)



- **Industrial processing** refers to transforming raw materials into products (e.g., steel manufacturing, food processing), which includes the **chemical manufacturing industry**
- **Industrial processing** accounted for **33%** of total fluoropolymer use in 2022 (450 kt), a share that has remained **stable** in recent years
- **Other sectors** include healthcare, aerospace, and consumer goods

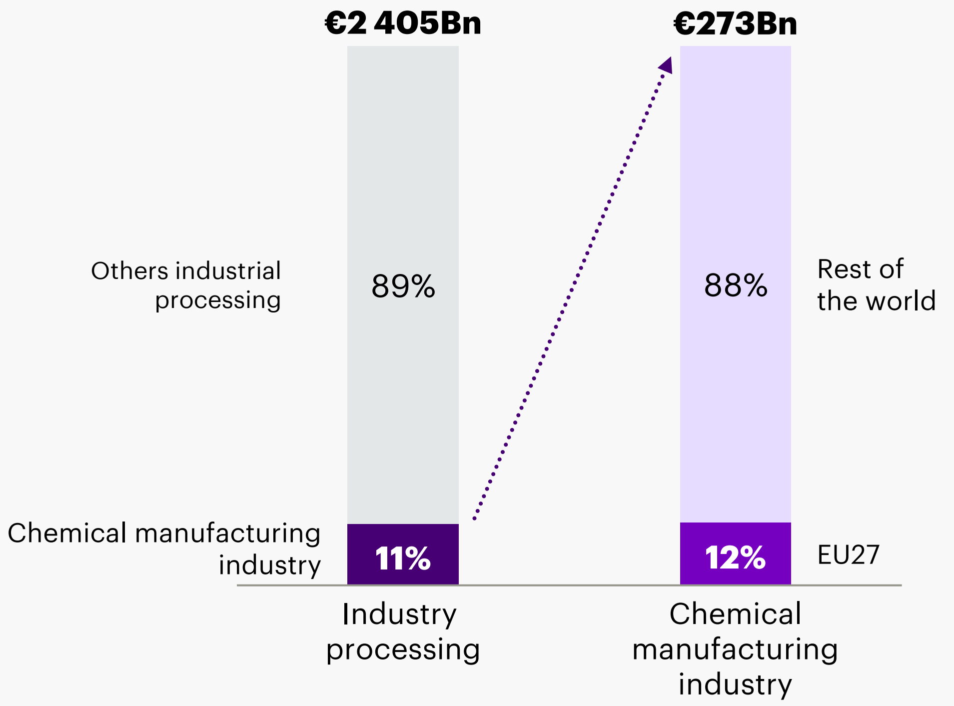
Industrial processing, including the chemical manufacturing sector, accounts for 33% of global fluoropolymers use

Source:Grand View Research, Accenture research and analysis

Fluoropolymer inventory

Annual use - Chemical manufacturing industry CAPEX & EU share

CAPEX in the industrial processing and chemical manufacturing industry
(2022)
Billions of Euros, %



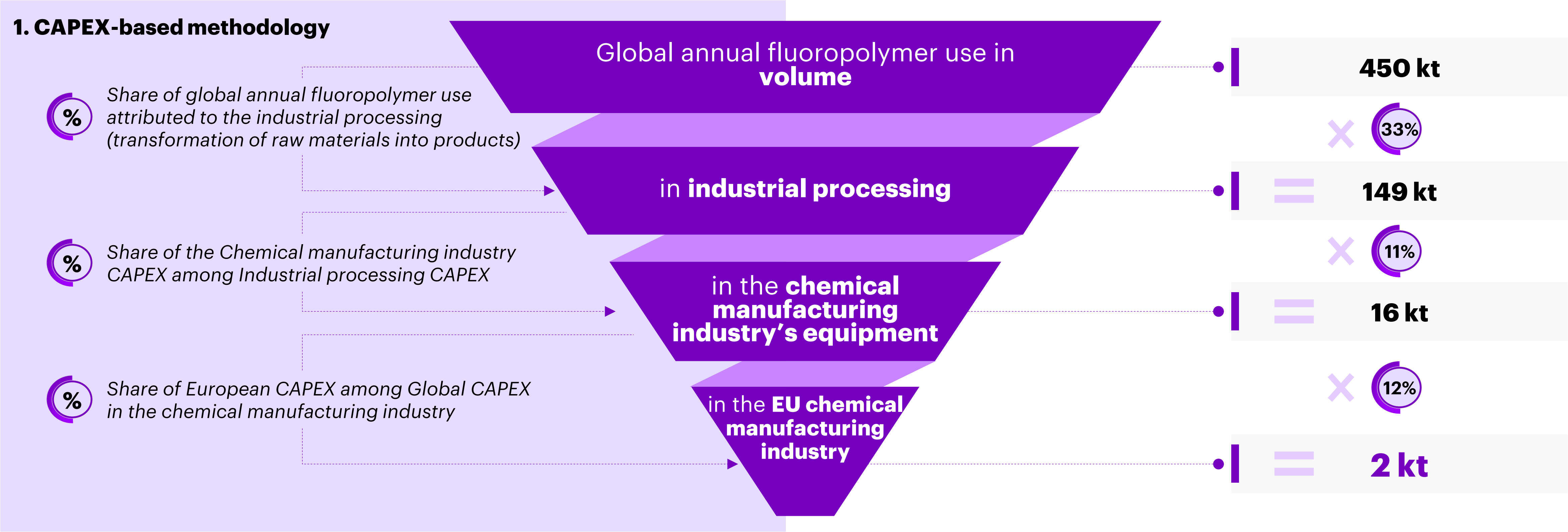
- In 2022, the capital expenditure (CAPEX) of the industrial processing sector totaled **€2,405Bn**. Of this, **€273Bn, representing 11%,** was invested in the **chemical manufacturing industry**
- Within this segment, the **European Union represented 12% (€33Bn)** of the global chemical manufacturing CAPEX

Chemical manufacturing accounts for 11% of industrial CAPEX
EU represents 12% of Chemical manufacturing CAPEX

Source: Grand View Research, Accenture research and analysis

Fluoropolymer inventory

Annual use – CAPEX-based methodology result

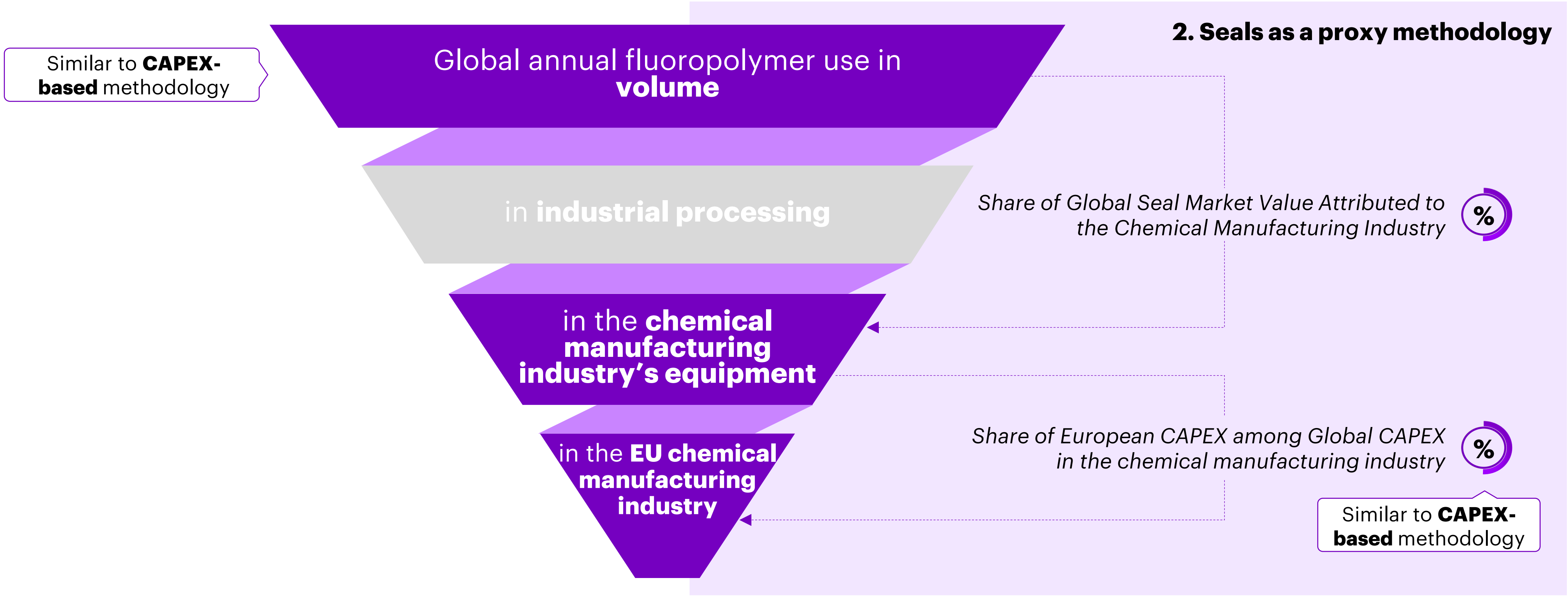


The EU chemical manufacturing industry accounts for 2 kt of annual fluoropolymer use

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

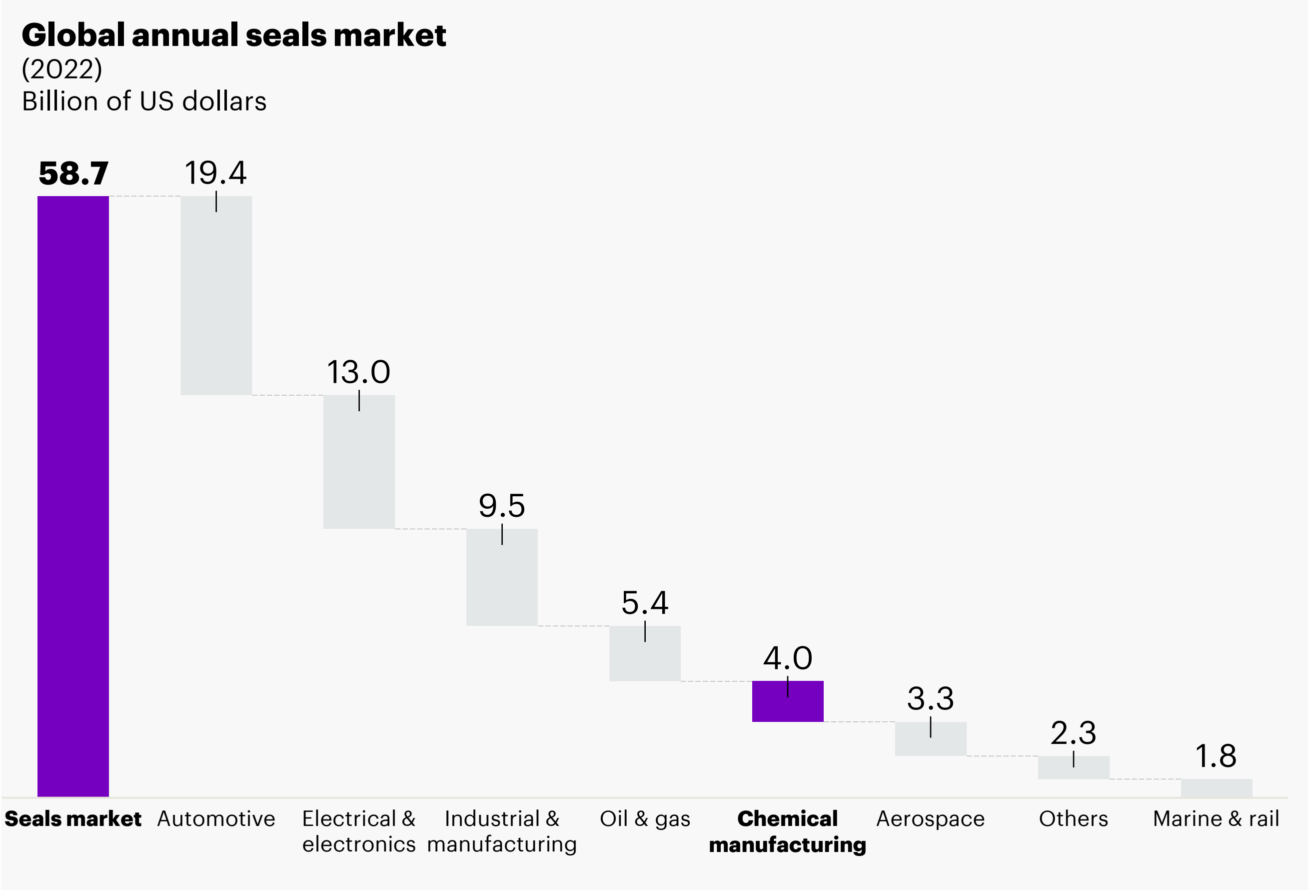
Annual use – Seals as a proxy methodology



Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Annual use – Chemical manufacturing seals market



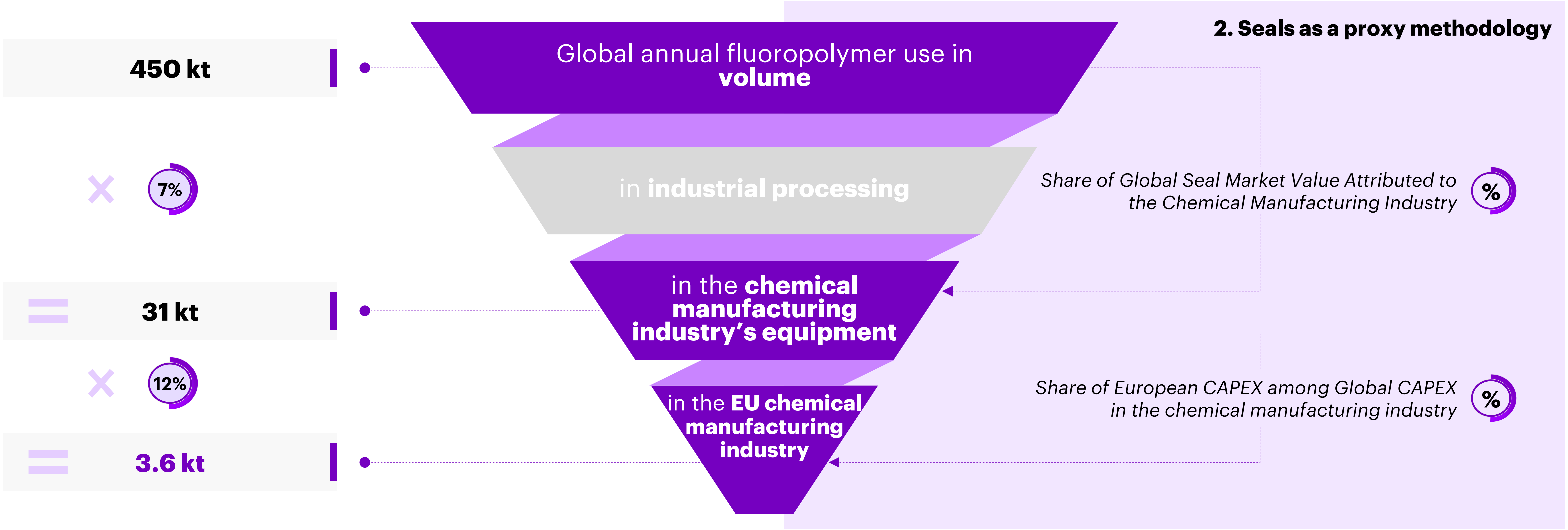
- In 2022, the **global seals market** was estimated to be worth around **$58.7Bn**
- The **chemical manufacturing sector** accounted for approximately **$4Bn** in seals demand, representing about **7% of the total market**

Annual chemical manufacturing industry accounts for 7% of global seals market

Source: Grand View Research, Accenture research and analysis

Fluoropolymer inventory

Annual use – Seals as a proxy methodology results



Based on Seals as a proxy analysis, the EU chemical manufacturing sector accounts for 4 kt of annual fluoropolymer use

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Methodology

Fluoropolymer inventory is calculated by multiplying the **annual use** by the **average replacement cycle** of elements containing fluoropolymer in EU chemical manufacturing plants

2.0 – 3.6 kt per year

Annual use

of fluoropolymer across equipment in the EU chemical manufacturing plants

Based on Top-down approach through **CAPEX** and **gasket** (proxy) methodologies

×

Average replacement cycle (years)

of elements containing fluoropolymer in a plant

Based on **survey answers** and **expert estimations**

FOCUS ON FOLLOWING SLIDE

=

Fluoropolymer Inventory (kt)

in use and in stock across the equipment of the EU chemical manufacturing industry

Fluoropolymer inventory

Average replacement cycle

Elements	Average share by fluoropolymer weight	Average replacement cycle *(years)*	[Min – Max] replacement range *(years)*
Piping	45%	12	[5 - 33]
Valves	26%	8	[3 - 26]
Gaskets	25%	7	[2 - 17]
Expansion joints	2%	9	[4 - 21]
O-rings	1%	6	[2 - 11]
Others*		Not included as it represents a minor share	
Overall		**9.6 years**	

Value confirmed through expert interviews

The average replacement cycle of elements containing fluoropolymers in a plant is estimated to be 10 years

Fluoropolymer inventory

Fluoropolymers inventory result

2.0 – 3.6 kt per year

Annual use

of fluoropolymers across equipment in EU chemical manufacturing plants

×

9.6 years

Average replacement cycle

of elements containing fluoropolymer in a plant

=

19 – 35 kt

Fluoropolymers Inventory (kt)

in use with and in stock for the equipment of the European chemical manufacturing industry

Representing on average 1.5– 2.7 t per plant

Based on Top-down approach through **CAPEX** and **gasket** (proxy) methodologies

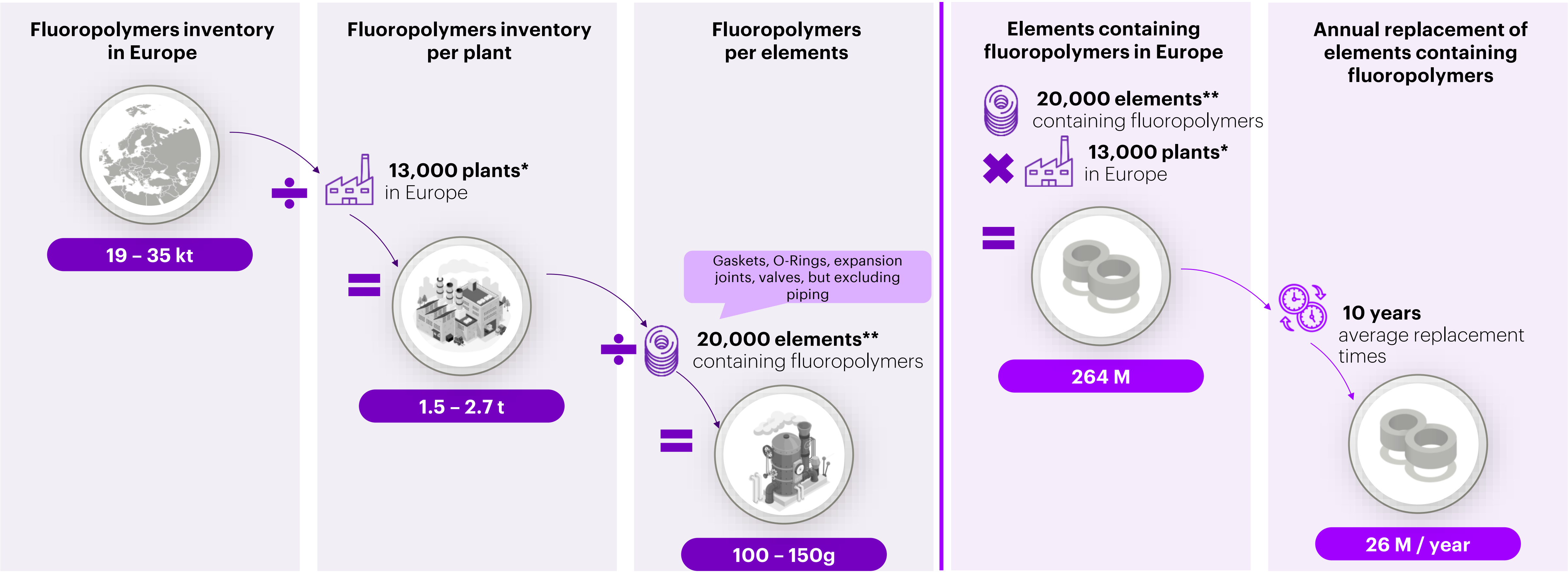
Based on **survey answers** and **expert estimations**

The fluoropolymers inventory across equipment in the EU chemical manufacturing plants is estimated between 19 – 35 kt

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Estimated weight of fluoropolymers per element in a plant

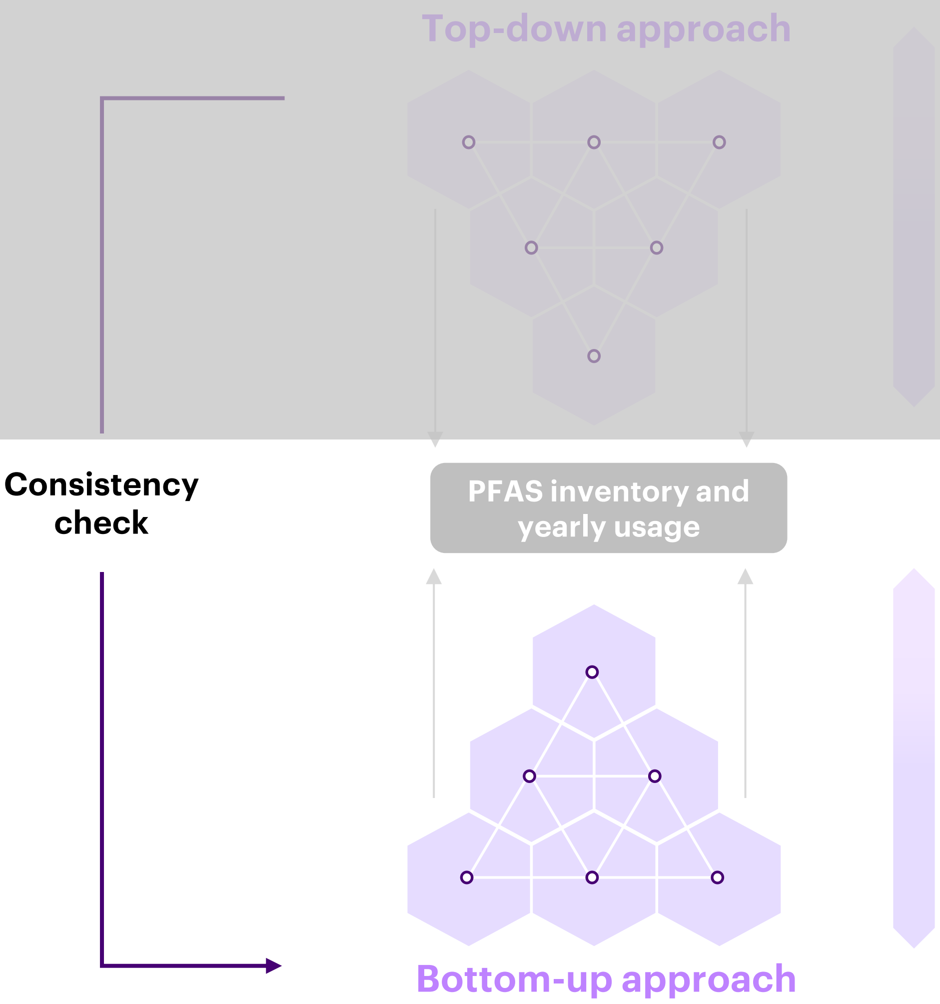


On average, each of the approximately 20,000 fluoropolymer-containing elements in a plant contains around 150 grams

Note: *Considering 13k plants monitored by the EEA in terms of emissions in 202
Source: Accenture research, interviews and analysis

PFAS inventory

Focus on bottom-up approach



- The **overall quantity of PFAS use per year across all sectors** is estimated
- To **approximate annual use in EU chemical manufacturing plants**, the analysis considers the EU chemical manufacturing industry's share of global capital expenditures (CAPEX)
- The data is sourced from **commercial databases, desk research, and expert interviews**

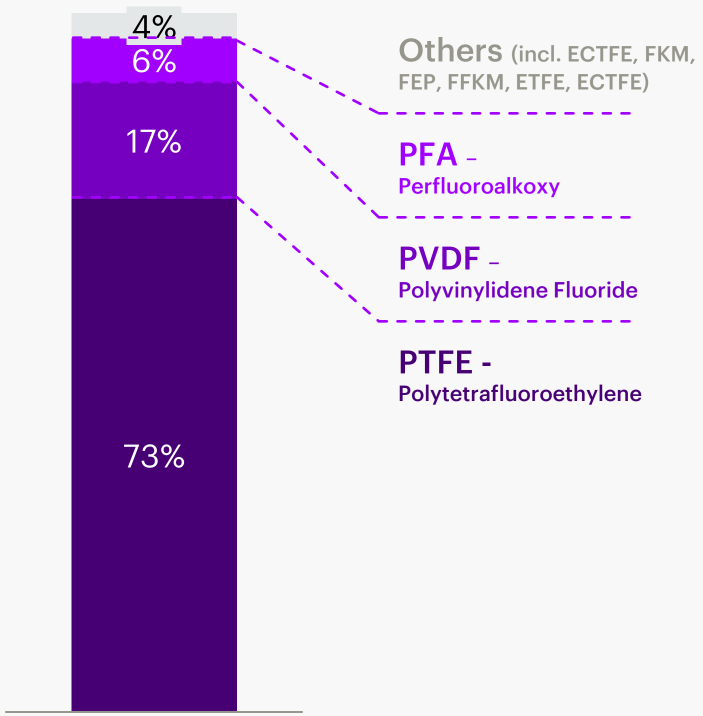
- The survey response covering 470 plants of Cefic members seeks to understand with a **high level of granularity** the **presence and type of PFAS** across equipment in EU chemical manufacturing plants (PFAS weight, number of equipment,...)
- The survey also analyzes **the average replacement cycle of equipment**, to estimate the annual use of PFAS in the EU chemical manufacturing industry
- The insights are primarily sourced from **survey results**

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Average share of fluoropolymers by type in a plant

Average share of fluoropolymers by type
Percentage by fluoropolymer weight*



- **PTFE on average is the most used fluoropolymer (73%)** due to its wide range of thermal resistance, strong chemical and mechanical durability
- **PVDF (17%)** is used in applications demanding **greater rigidity and mechanical strength** than PTFE
- **PFA (6%)** combines PTFE's **thermal resistance** with higher **flexibility** for challenging mechanical applications
- **Fluoropolymers used across equipment in EU manufacturing chemical plants mirror the annual global fluoropolymers market**, with PTFE being the most used PFAS, followed by PVDF

"… PTFE remains the most commonly used fluoropolymer, with chemical manufacturing sector being no exception …"

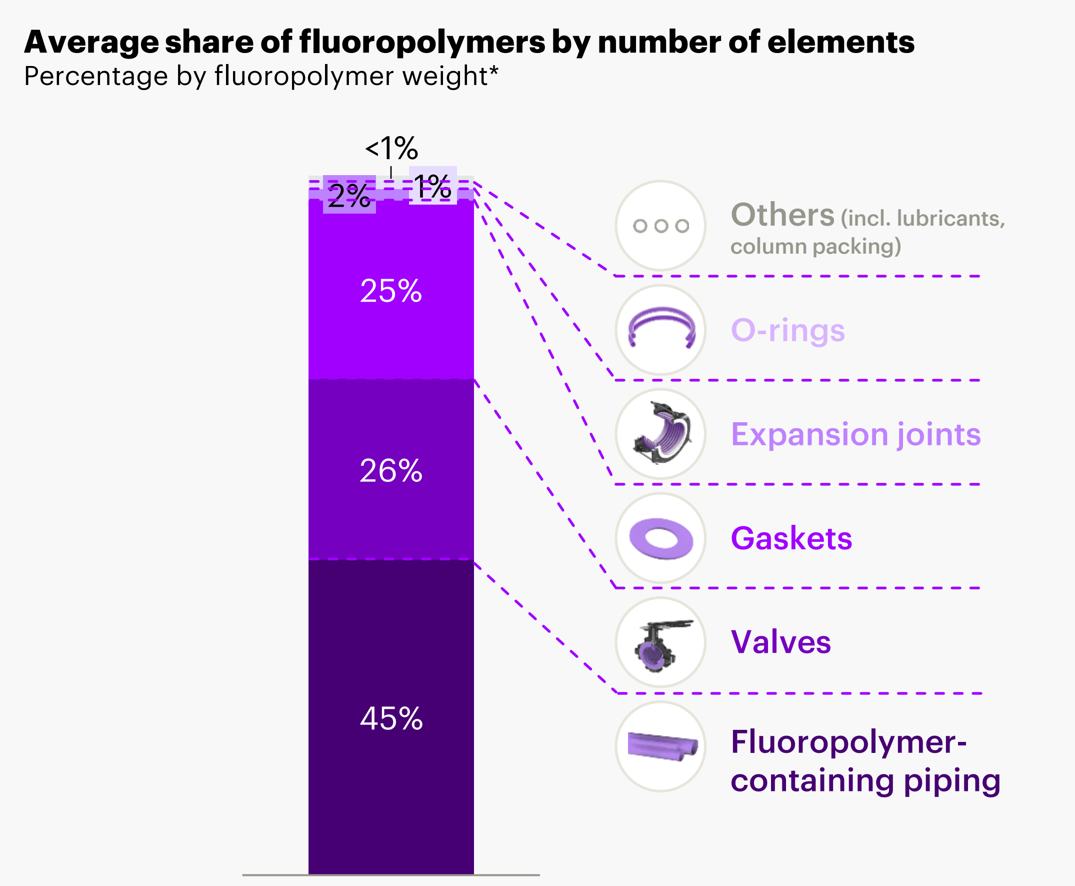
Fluoropolymer expert

PTFE is on average the most used fluoropolymer in EU chemical manufacturing plants, accounting for 73% in weight

Note: *Calculation based on the different diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Average share of fluoropolymers by number of elements in a plant



- **Fluoropolymer containing pipes** account for the **largest share of fluoropolymer weight (45%)** due to high fluoropolymer content
- **Valves (26%)** contain various fluoropolymers for sealing and chemical protection, making them a **major contributor** to overall fluoropolymer weight
- **Gaskets (25%)**, despite having small individual fluoropolymer weight, are used in **large quantities**, resulting in **significant** overall weight
- **Expansion joints (2%)**, used in **small quantities**, contribute **minimally** on average to the total fluoropolymer weight in a plant
- **O-rings (1%)** have a lower fluoropolymer content compared to gaskets and are used in **smaller quantities**, thus having **limited impact**
- **Others (incl. lubricants, column packing)** represent **under 1%** on average of total fluoropolymer weight in a plant

Typical average quantity per plant

14,000	4,300	1,800	200	0.4 km
Gaskets	O-rings	Valves	Exp. joints	Piping

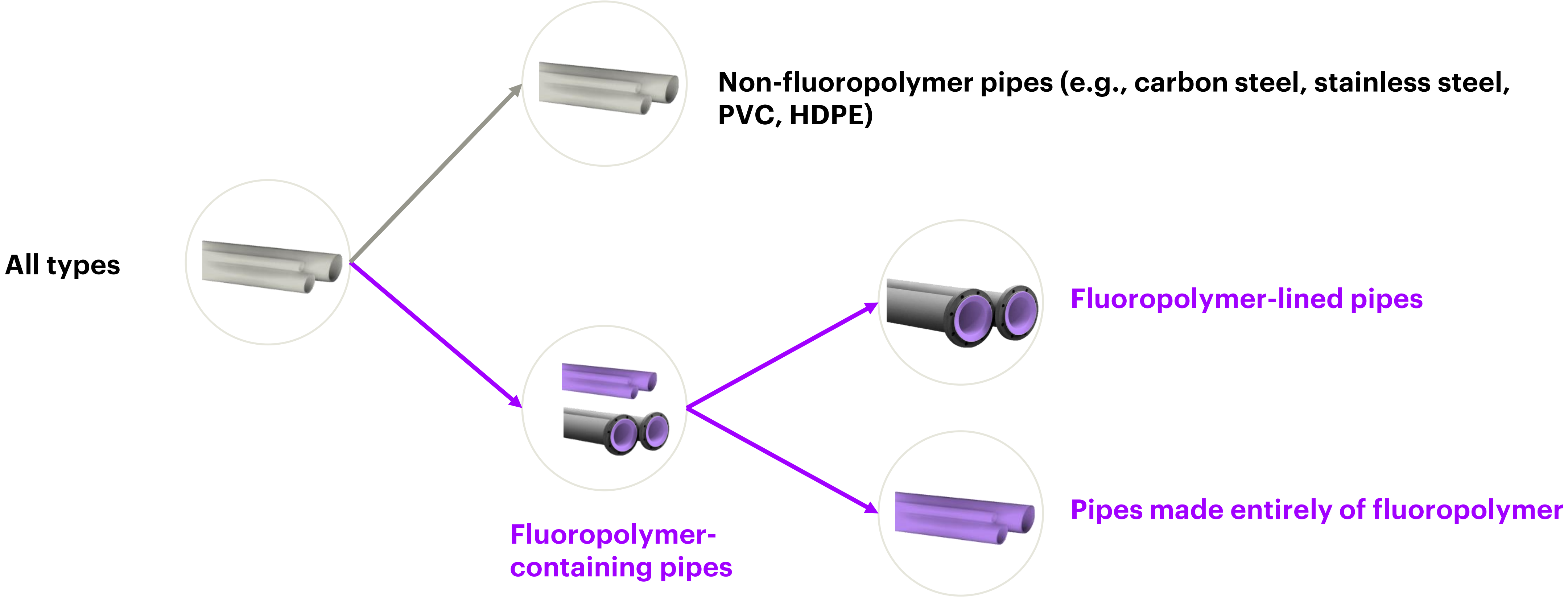
Piping, valves, and gaskets are the main elements containing fluoropolymers in EU chemical manufacturing plants

Note: *Calculation based on the different diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Different pipe types

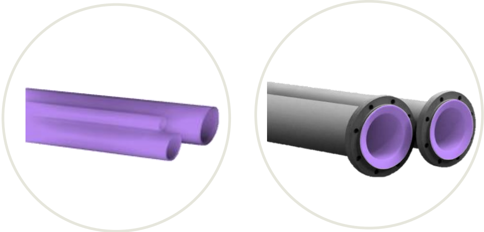
Various types of pipes exist, but this study focus exclusively on those containing fluoropolymers: fluoropolymer-lined pipes and pipes made entirely of fluoropolymer



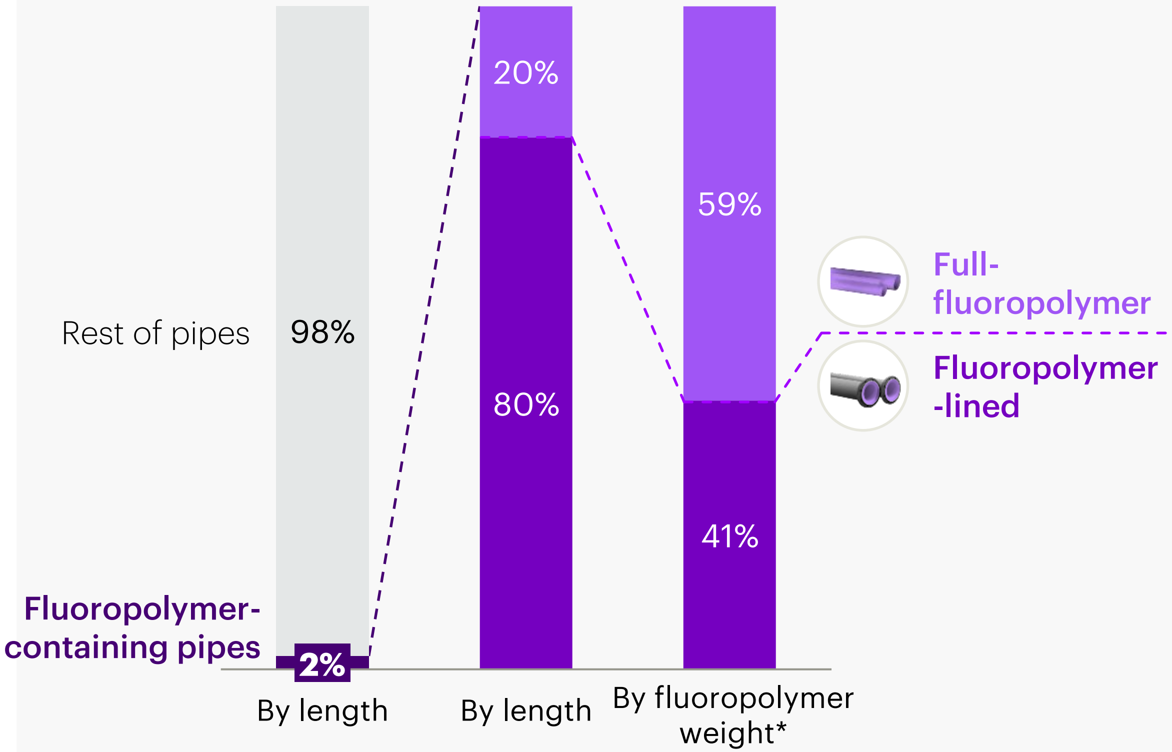
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Fluoropolymer-containing pipes



Average share of fluoropolymer pipes (EU)
Percentage by length and by fluoropolymer weight*



Fluoropolymer-containing pipes fluoropolymer inventory at EU level

9- 16 kt

- Pipes make use of fluoropolymers to increase chemical resistance and overall durability, but **their use remains minor (2%)** compared to non-fluoropolymer pipes (e.g., carbon steel, stainless steel, PVC, HDPE)
- **In fluoropolymer-containing pipes, full-fluoropolymer pipes** represent a **small share (20%) compared to fluoropolymer-lined pipes (80%) in terms of lengths**, but **large share of fluoropolymer weight (59% compared to 41%)** – the difference is explained by the low weight of fluoropolymer in lining
- **Pipes with fluoropolymer coatings are excluded** from the analysis due to a lack of data regarding their usage. Additionally, coatings are typically less than 1mm thick and **contain little percentage of fluoropolymers**, making their **weight share minor**

Typical average quantity per plant

0.4 km	21 km
Fluoropolymer pipes	Total piping

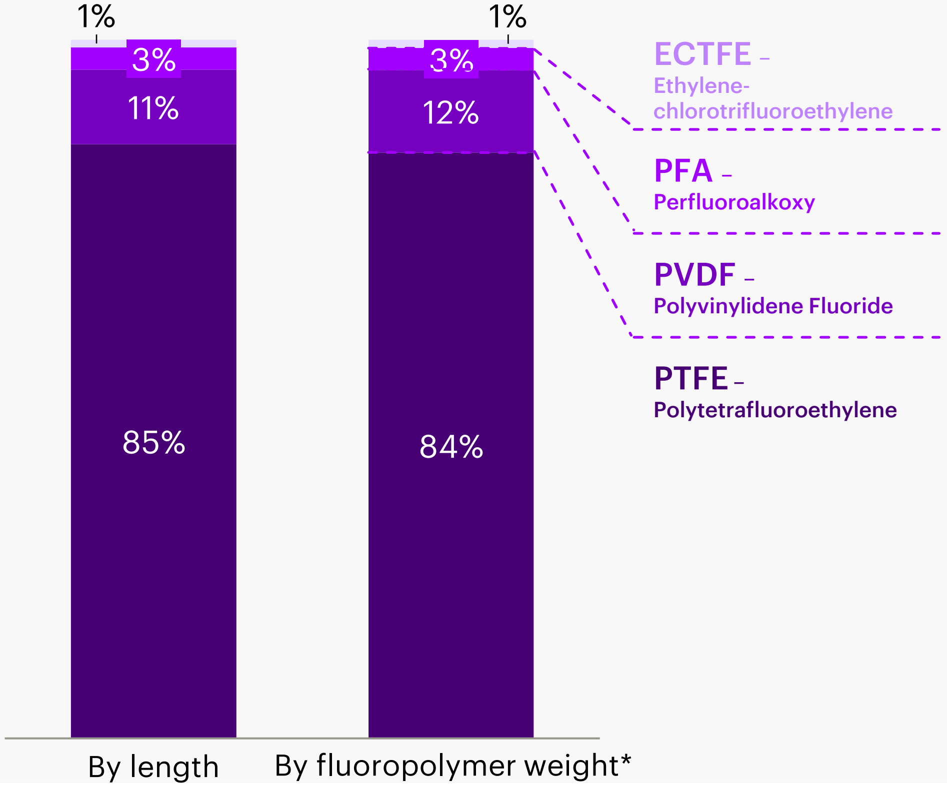
Fluoropolymer-containing pipes make up only about 2% of total piping but remain the main source of fluoropolymers by weight in EU chemical manufacturing plants

Note: *Calculation based on the different pipes diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Fluoropolymer-lined pipes

Average share of fluoropolymer for lined pipes (EU)
Percentage by length and by fluoropolymer weight*

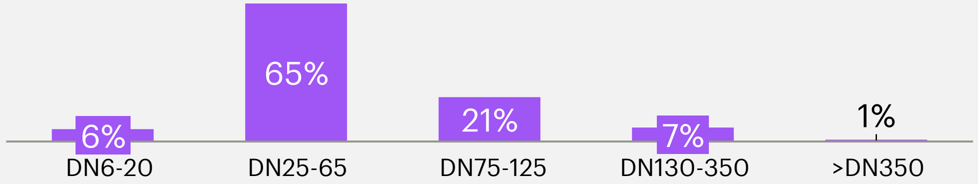


Fluoropolymer-lined pipes fluoropolymer inventory at EU level

4 – 6 kt

- **Fluoropolymer lining are mainly used to increase the chemical and thermal resistance** of piping, whose structural strength is provided by metal
- **PTFE (84% weight) is the preferred lining material** due to its broad chemical compatibility and superior thermal resistance compared to other fluoropolymers
- Diameters predominantly **concentrated in the medium DN sizes**- *DN (Nominal Diameter) is a standardized pipe size designation that approximately corresponds to the internal diameter measured in millimeters*

Distribution of fluoropolymer-lined pipe by DN
Percentage by DN



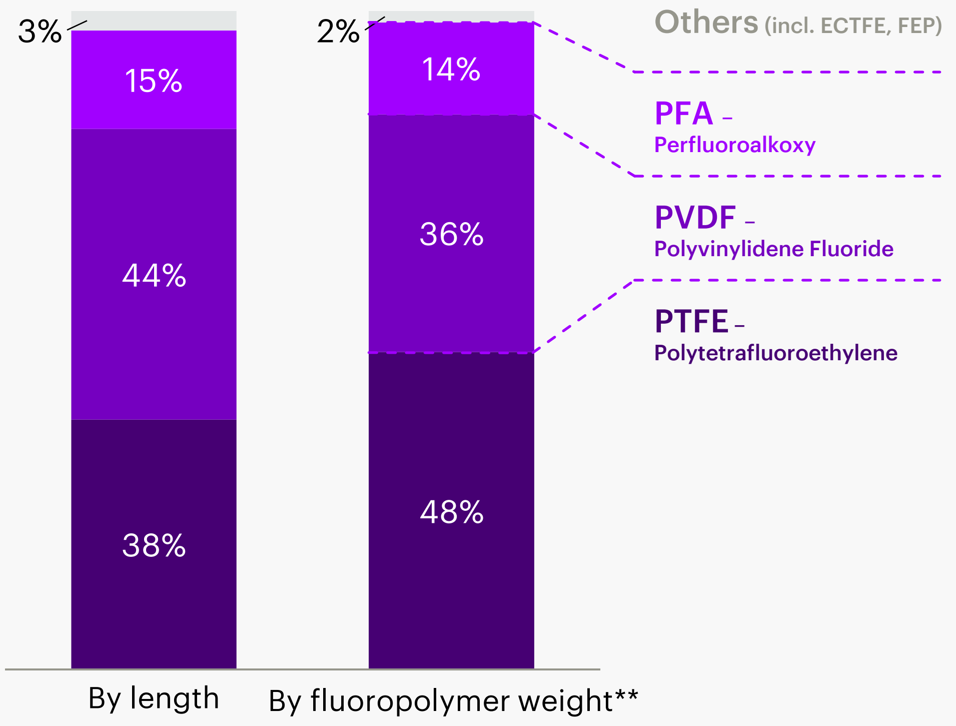
PTFE is the predominant fluoropolymer used in lined pipes in the European chemical manufacturing industry

Note: *Calculation based on the different pipes diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Full-fluoropolymer pipes

Average share of fluoropolymer for full fluoropolymer pipes (EU)
Percentage by length and by fluoropolymer weight*

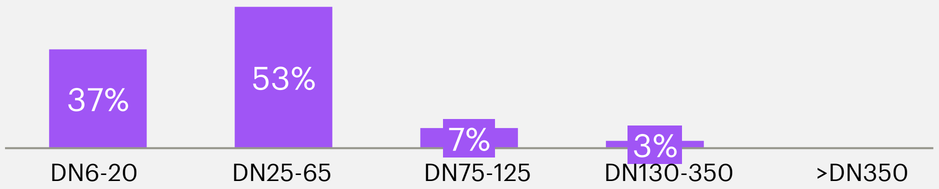


Full-fluoropolymer pipes fluoropolymer inventory at EU level

5 – 10 kt

- **Full-fluoropolymer pipes** lack metal structure and focus specifically on mechanical properties, resulting in **more balanced mix of fluoropolymer types**
- **PTFE (48% weight)** is preferred for full-fluoropolymer pipes because of its superior chemical compatibility and thermal resistance compared to other fluoropolymers
- **PVDF (36% weight)** are used when mechanical strength and **rigidity** are critical, while **PFA (14% weight)** provides adaptability due to flexibility for specific applications
- Full-fluoropolymer pipes are mostly **used in small DN sizes** - *DN (Nominal Diameter) is a standardized pipe size designation that approximately corresponds to the internal diameter measured in millimeters*

Distribution of fluoropolymer-lined pipe by DN
Percentage by DN



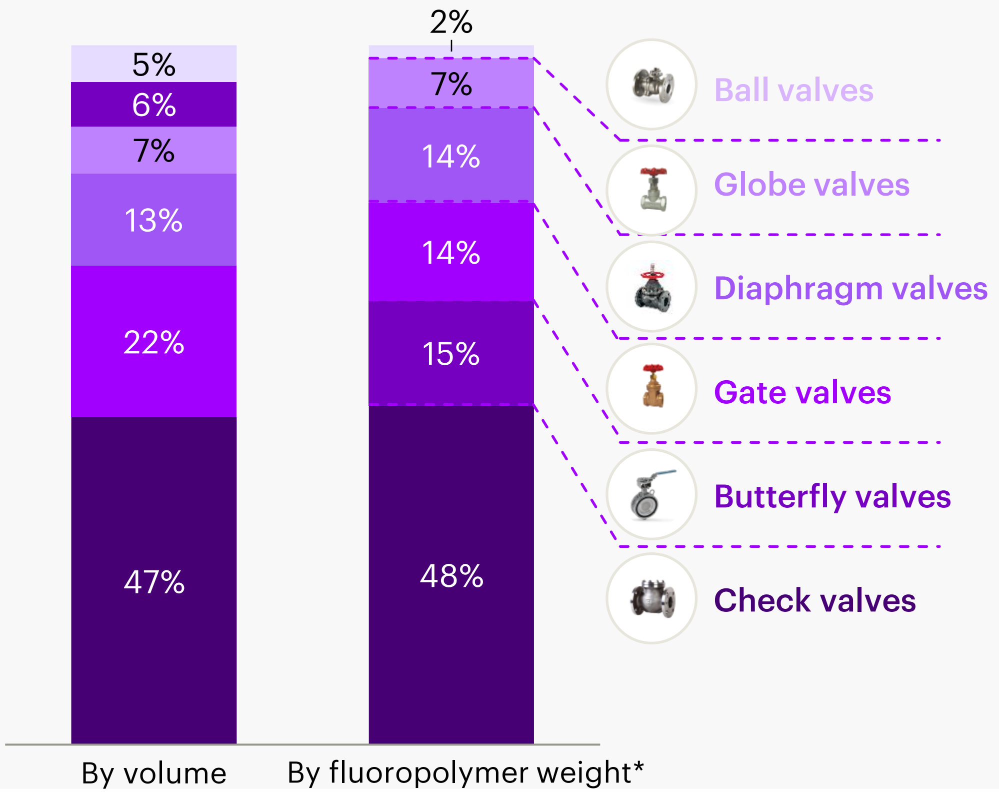
Full fluoropolymer pipes are primarily composed of PTFE, PVDF and PFA

Note: *Calculation based on the different pipes diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Valves

Average share of fluoropolymer weight for valves (EU)
Percentage by volume and by fluoropolymer weight*



Valves fluoropolymer inventory at EU level

5 – 9 kt

- **Check valves (48%) represent nearly half of the total PFAS weight in average in a plant**, reflecting their key role in ensuring process safety by passively preventing backflow
- **Butterfly valves (15% weight) are mainly used for large diameters**, which explains their high fluoropolymer weight despite their small quantity in a plant
- In addition, valves contain multiple types of fluoropolymers, but **PTFE remains the most common**

Typical average quantity per plant

1,800
Valves

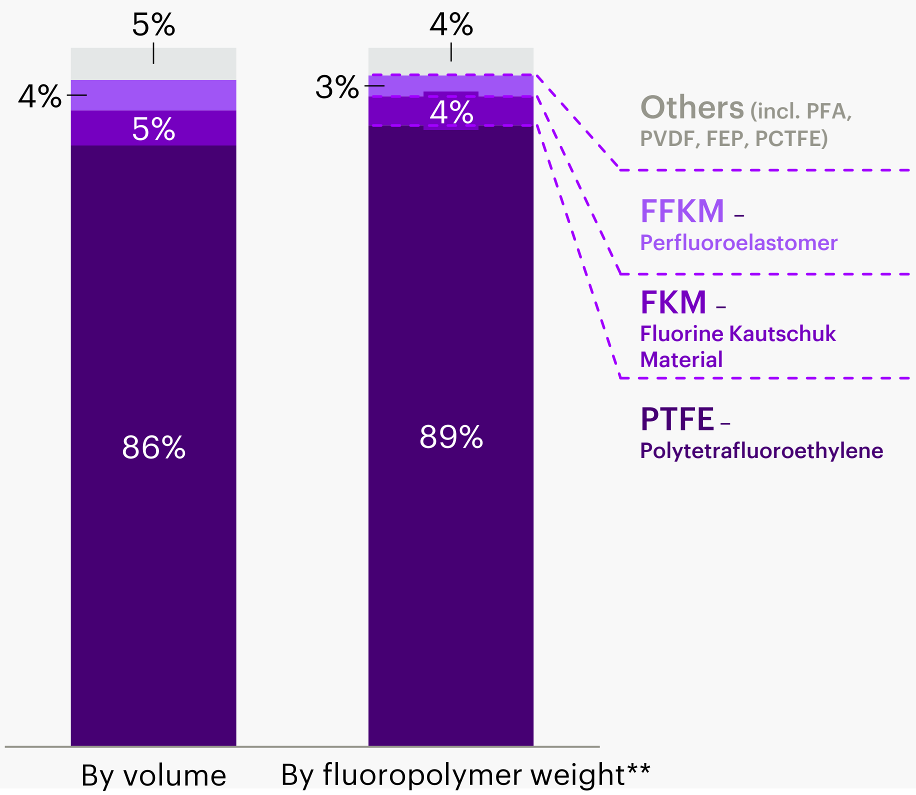
Fluoropolymers are present in all types of valves in EU chemical manufacturing plants

Note: *Calculation based on the different valves diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Gaskets

Average share of fluoropolymer for gaskets
Percentage by volume and by fluoropolymer weight*



Gaskets fluoropolymer inventory at EU level

5 – 9 kt

- Gaskets are used in **static and dynamic applications**, where rigid materials are preferred for sealing between two surfaces
- **PTFE (89% weight) is the most common fluoropolymer in gaskets** due to its wide range of thermal resistance, as well as chemical and mechanical durability
- Additionally, both **ring-type and full-face type gaskets** show **similar fluoropolymers distribution**

Typical average quantity per plant

14,000

Gaskets

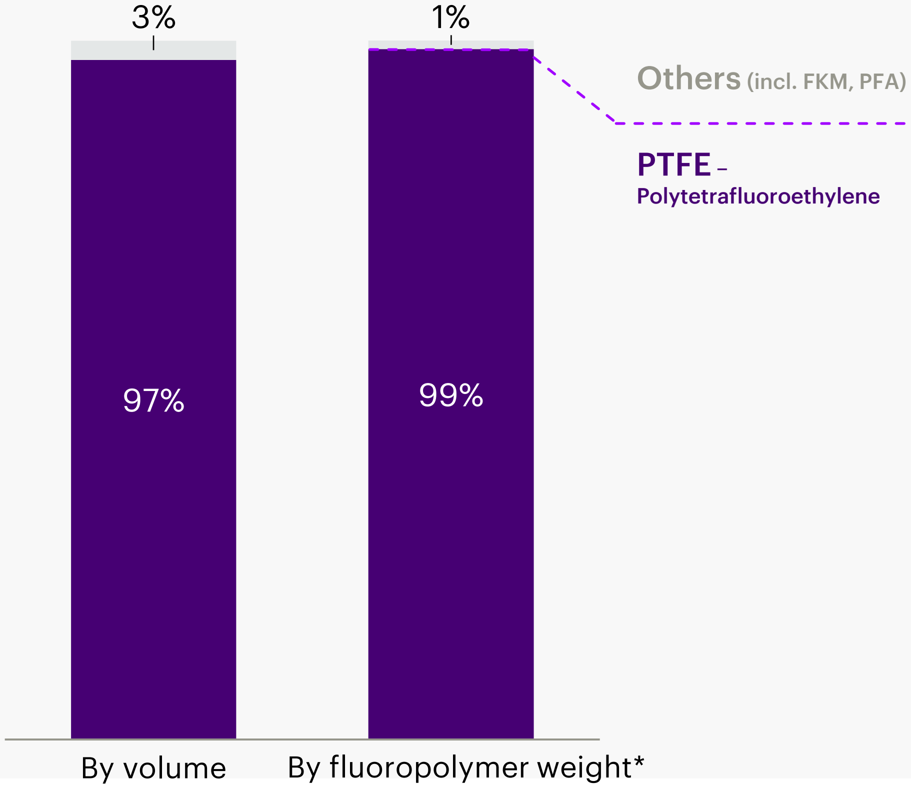
PTFE is the most used fluoropolymer for gaskets, making up about 90% of their weight in a plant

Note: *Calculation based on the different gasket diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Expansion joints

Average share of fluoropolymer for expansion joints
Percentage by volume and by fluoropolymer weight*



Expansion joints fluoropolymer inventory at EU level

0.3 - 0.6 kt

- **Expansion joints absorb thermal expansion, vibration, and mechanical movement** to protect piping systems and equipment from stress and damage
- **PTFE** is the most common fluoropolymer in expansion joints, due to its **resilient material properties** and **adequate flexibility**
- **FKM** and **PFA, the other fluoropolymers identified in expansion joints**, are reserved for specific uses and smaller diameters, because of their high cost

Typical average quantity per plant

200

Exp. joints

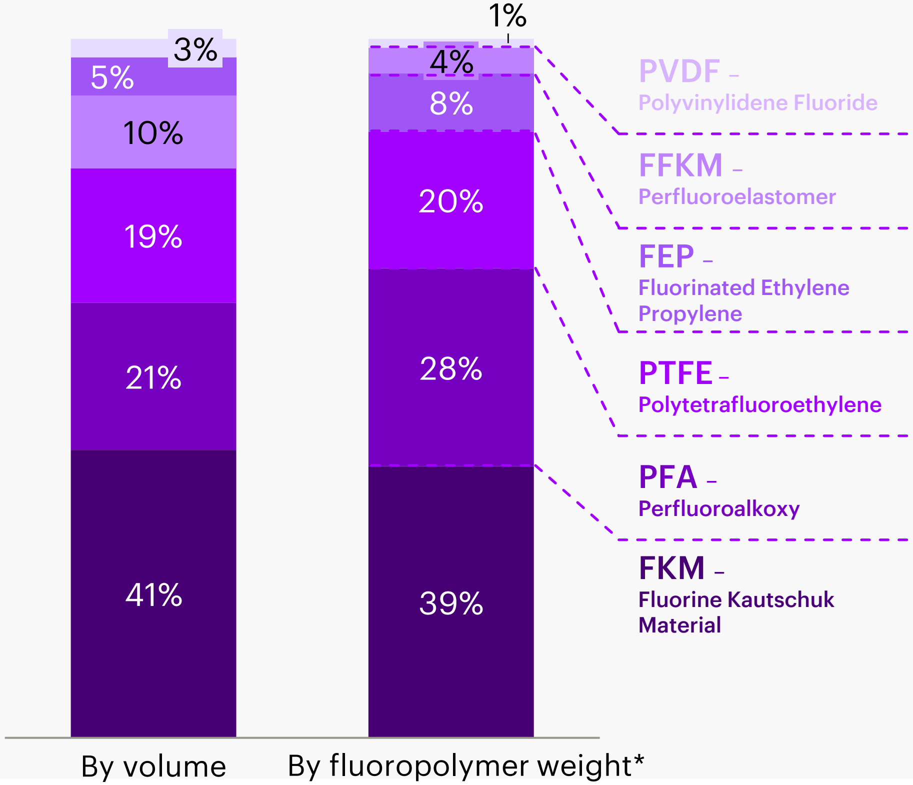
PTFE is the most used fluoropolymer for expansion joints, making up nearly all the total weight

Note: *Calculation based on the different expansion joints diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

O-rings

Average share of fluoropolymer for O-rings
Percentage by volume and by fluoropolymer weight*



O-ring fluoropolymer inventory at EU level

0.2 - 0.3 kt

- O-rings are used in **different configurations** (e.g., valves stems, pump shafts, instrument connections) compared to gaskets, and require materials that offer flexibility and high sealing performance, which explains the **high presence of fluoroelastomers (FKM at 39% weight)**
- **PFA (28% weight) and FEP (8% weight)** are chosen for applications requiring **superior chemical resistance and durability,** often serving as an **encapsulation layer** for FKM to combine flexibility with enhanced resistance

Typical average quantity per plant

4,300

O-rings

For O-rings, fluoropolymer use is varied, with FKM, PFA, and PTFE accounting for about 87% of their total weight in a plant

Note: *Calculation based on the different O-ring diameters and types provided in the survey
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Others: Lubricants

Lubricants (incl. greases) composition

Base oil
70-90% of the total composition in weight
Possible presence of PFAS

Thickeners
2-20% of the total composition in weight
Possible presence of PFAS

Additives
2-10% of the total composition in weight
Possible presence of PFAS

- **The proportion and formulation of lubricants vary significantly from one product to another** depending on their application
- Due to the complexity of these variations and limited traceability, **providing a precise estimate of PFAS concentrations in lubricants across all EU chemical manufacturing plants is challenging**
- However, **PFAS-containing lubricants** are estimated at **30 to 40 liters per plant**, **and PFAS-containing greases** ranging from **20 to 30 kg per plant**

PFAS concentration varies significantly

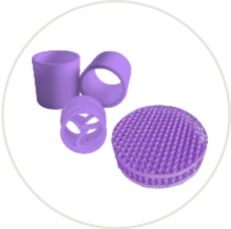
- PFPE (non-fluoropolymer), PTFE and PCTFE (fluoropolymers) used
- Rare lubricant formulations can reach nearly 100% PFAS, while others are completely PFAS-free or contain only small percentages
- High PFAS concentration used in applications requiring chemical resistance, thermal stability and long-term durability (e.g. lubricants in circuit breakers)
- Low PFAS concentrations (e.g., lubricants with PTFE micro-powder - additive) to enhance wear lubrication under pressure and heat

Lubricants account for less than 1% of the total PFAS inventory in the EU chemical manufacturing industry

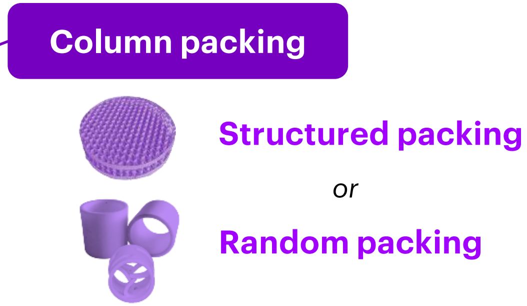
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Others: Column packing



Column packing



Packing employed in columns to increase the contact surface between liquid and vapor phases in column

- Packing might be made of fluoropolymers to increase **longevity**, **non-stick properties**, or deal with **corrosive applications**
- 95% of column packing are made of non-fluoropolymer material, mostly stainless steel. The **remaining 5% are made of fluoropolymers**
- The fluoropolymer weight of column packing in the EU chemical manufacturing industry is **small due to their rare usage**

"… Chemical manufacturing companies primarily use column packing made of stainless steel, with fluoropolymer-based packing being employed only in very rare and specific cases …"

Column packing expert

Fluoropolymers are rarely used in column packings, and their presence therefore remains selective at plant level

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Other equipment

Batteries

- While the reactive cores of most batteries do not contain **PFAS**, they **are typically found in supporting components** like gaskets and binders. In **lithium batteries**, however, PFAS may also be **present in the core**, leading to higher overall content
- **Other types of batteries are six times more frequently used** than lithium batteries in chemical manufacturing plants

Electric wires

- Fluoropolymers are commonly used in **wire insulation and jacketing** due to their insulating and flexible properties, as well as their resistance to high temperatures and chemicals
- **PTFE** is the most used type of fluoropolymer

Circuit breakers

- PFAS-based lubricants are used in circuit breakers for **non-flammability, friction-reducing properties, and ability to ensure long-term stability and performance** under extreme environmental conditions

PFAS can also be found in power and utilities elements such as batteries, electric wires, and circuit breakers

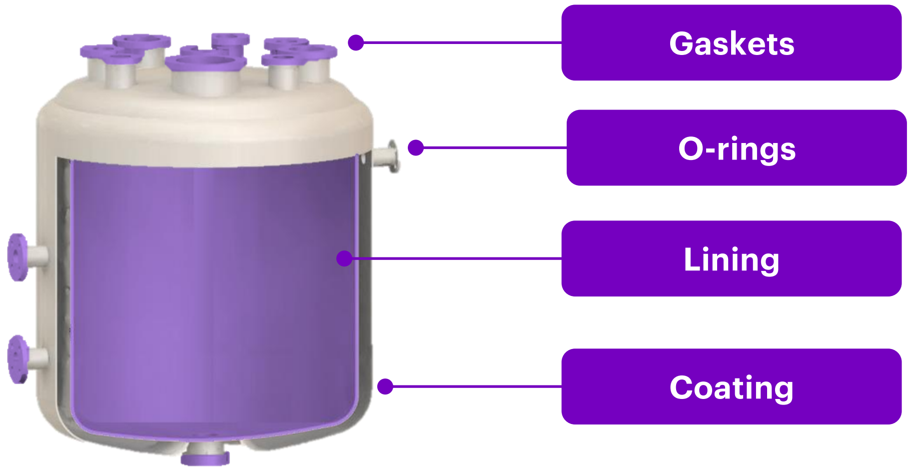
Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Illustrative

Reactor Use Case Illustration

Fluoropolymers are present in key elements across equipment – Example of reactors



Reactor use case illustration

- Fluoropolymers are found in equipment in **specific locations**: **gaskets, O-rings, coating and lining**
- **Gaskets** are installed at reactors' **nozzles** to ensure tight sealing between flanged connections
- **O-rings** are used in smaller scale sealing applications such as for reactors' **thermocouples**
- **Coating** is applied to **external surfaces** of reactors to provide protection against environmental factors
- **Lining** covers **internal surfaces** of reactors, protecting them from aggressive chemicals

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Average quantity of equipment per plant *– typical average, values may vary across chemical industries*

Vessels

70
Drums

55
Heat exchangers

20
Reactors

15
Mechanical separators

5
Columns

Segment specific
Crystallizers

Segment specific
Dryers

Segment specific
Evaporators

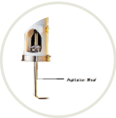
Segment specific
Fired heaters

Other equipment

1,700
Instruments

400
Pumps

50
Fans/turbines



35
Agitators

30
Compressors

25
Refrigeration systems

10
Membrane filtration systems

10
Conveyors

Segment specific
Crushers

Segment specific
Cooling towers

Segment specific
Grinders

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Coating, lining, O-rings and gaskets presence in vessels

Vessels	Coating	Lining	O-rings	Gaskets
Column	20 - 30%	40 - 50%	Survey reveals the use of fluoropolymers in O-rings and gaskets within equipment is widely acknowledged	
Crystallizers	50 - 60%	> 60%		
Drums	20 - 30%	40 - 50%		
Dryers	20 - 30%	30 - 40%		
Evaporators	20 - 30%	30 - 40%		
Fired heaters	40 - 50%	40 - 50%		
Heat exchangers	30 - 40%	40 - 50%		
Mechanical separators	20 - 30%	30 - 40%		
Reactors	30 - 40%	40 - 50%		

While gaskets and O-rings are standard across vessels, coatings and linings are used in a more selective manner

Source: Accenture research, interviews and analysis

Fluoropolymer inventory

Coating, lining, O-rings and gaskets in other equipment

Other equipment	Coating	Lining	O-rings	Gaskets
Agitator	30 - 40%	30 - 40%	Survey reveals the use of fluoropolymers in O-rings and gaskets within equipment is widely acknowledged	
Compressor	20 - 30%	20 - 30%		
Conveyor	30 - 40%	30 - 40%		
Cooling towers	20 - 30%	20 - 30%		
Crushers	30 - 40%	30 - 40%		
Fans/turbines	30 - 40%	30 - 40%		
Grinders	40 - 50%	30 - 40%		
Instruments	30 - 40%	30 - 40%		
Membrane filtration system	20 - 30%	30 - 40%		
Pumps	30 - 40%	40 - 50%		
Refrigeration system	30 - 40%	20 - 30%		

While gaskets and O-rings are standard across equipment, coatings and linings are used in a more selective manner

Source: Accenture research, interviews and analysis

F-gas inventory

Methodology

The **F-gas inventory** is calculated by multiplying the **annual use** by the **average replacement cycle** of F-gases in European chemical manufacturing plants

Annual use (kt per year)
of F-gases by the EU chemical manufacturing industry

×

Average replacement cycle (years)
of F-gases in EU chemical manufacturing plants

=

F-gases Inventory (kt)
in use in EU chemical manufacturing plants

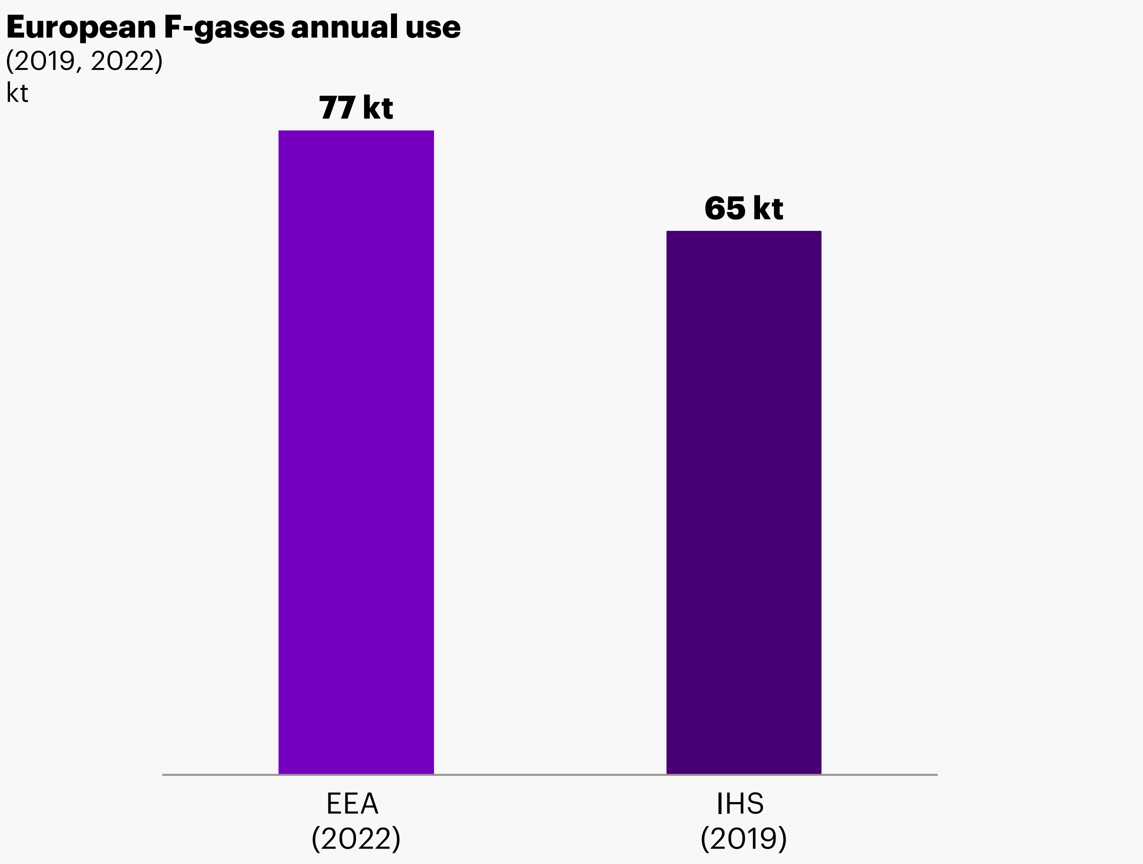
Based on **Top-down approach**

FOCUS ON THE FOLLOWING SLIDES

Based on **survey answers** and **expert estimations**

F-gas inventory

Annual use - European annual F-gases use



- Based on information from commercial market databases, we estimate the **European F-gases annual use to be around 70 kt:**
  - The European Environment Agency (EAA) estimated that European F-gases annual use was 77 kt in 2022
  - According to IHS Markit, the European F-gases annual use was 65 kt in 2019

"… F-gases use should be around 70 kt per year, with most of it being used in refrigeration and air conditioning …"

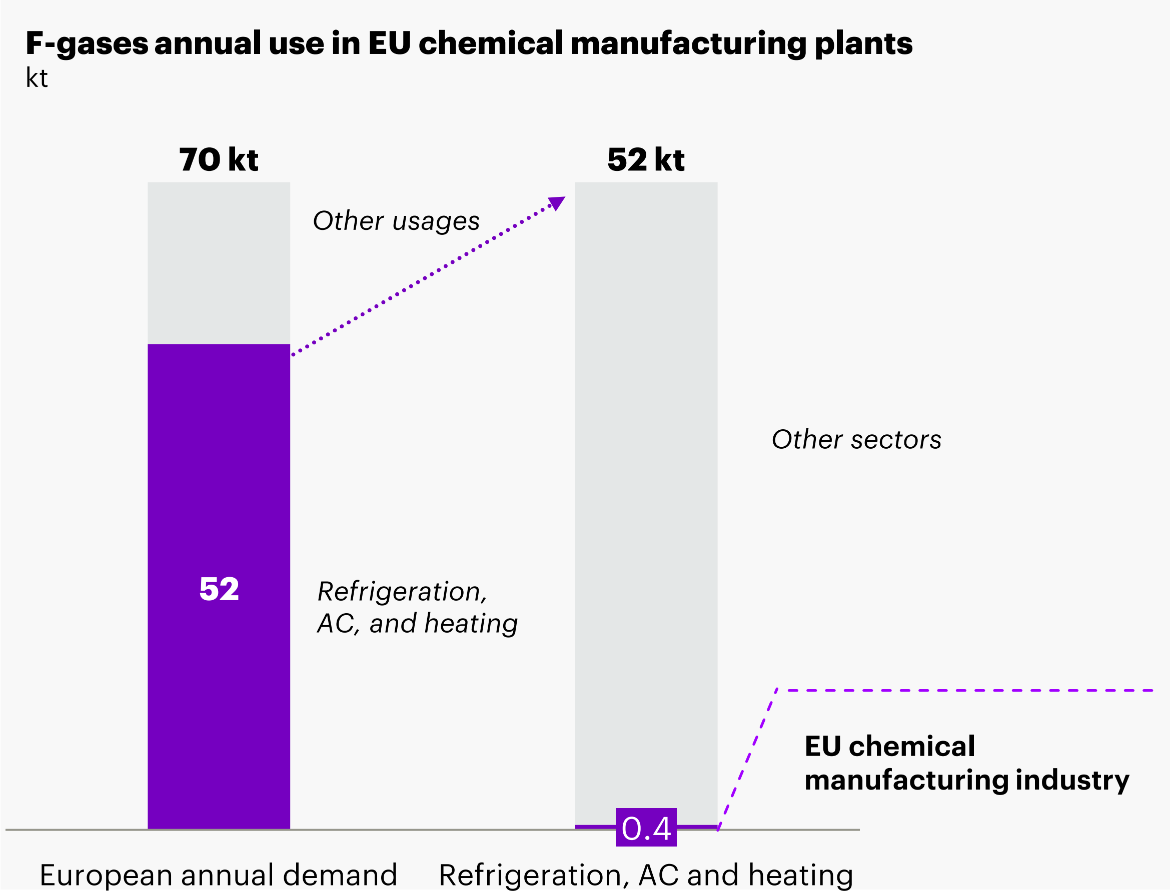
F-gases expert

The European F-gases annual use is estimated at 70 kt per year

Source: EEA, IHS Markit, Accenture research, interviews and analysis

F-gas inventory

Annual use - EU chemical manufacturing plants annual F-gases use



- Based on several commercial databases, **75% of F-gases are used in refrigeration, air conditioning (AC) and heating** applications
- **Other usages for F-gases** include as an additive to isolation foams, and in aerosols and sprays, such as medical inhalers
- Based on expert interviews, Accenture estimates that the share of **EU chemical manufacturing industry** is around **0.4 kt**, representing **less than 1%** of total volume of F-gases used for refrigeration, air conditioning and heating

F-gases annual use estimated at 0.4 kt per year across EU chemical manufacturing plants

Source: EEA, European Commission, Accenture research and analysis

F-gas inventory

Methodology

The **F-gas inventory** is calculated by multiplying the **annual use** by the **average replacement cycle** of F-gases in EU chemical manufacturing plants

0.4 kt per year

Annual use (kt per year)

of F-gases by the EU chemical manufacturing industry

Based on **Top-down approach**

×

Average replacement cycle (years)

of F-gases in EU chemical manufacturing plants

Based on **survey answers** and **expert estimations**

FOCUS ON FOLLOWING SLIDE

=

F-gases Inventory (kt)

in use in EU chemical manufacturing plants

F-gas inventory

Average replacement cycle

F-gases used in EU chemical manufacturing plants typically experience annual weight losses on average of **7-13%**

Replacing overall F-gases with the same type across a chemical manufacturing plant would likely require **10 years on average**

Estimation based under normal operating conditions, **excluding any PFAS-related regulations**

Replacing F-gases in EU chemical manufacturing plants takes around 10 years on average

Source: Accenture research, interviews and analysis

F-gas inventory

Results

0.4 kt per year

Annual use

of fluoropolymers across equipment in the EU chemical manufacturing plants

×

10 years

Average replacement cycle

of elements containing F-gases in a plant

=

4 kt

F-gases Inventory (kt)

in use in EU chemical manufacturing plants

Representing on average 0.3 t per plant

Based on **Top-down** approach

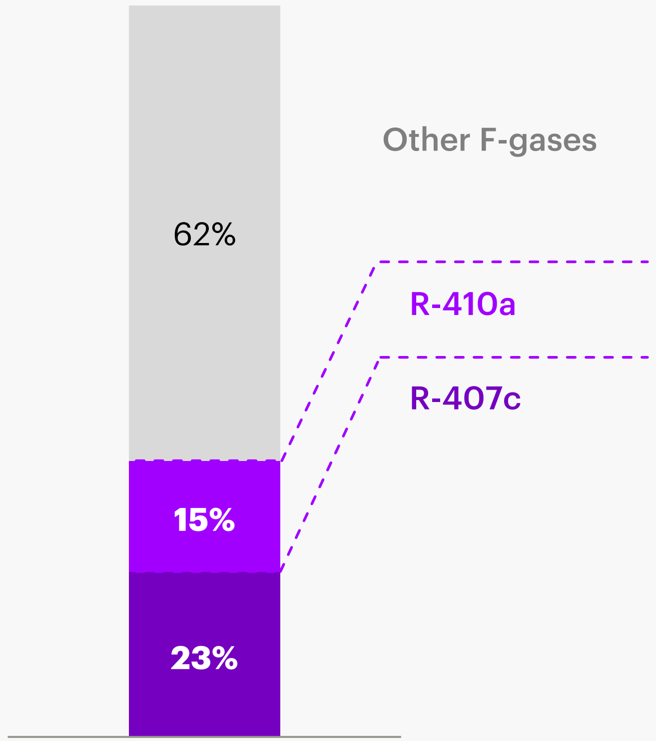
Based on **survey answers** and **expert estimations**

F-gases inventory is estimated at 4 kt across EU chemical manufacturing plants

F-gas inventory

Average share of F-gases by type in plant

Average weight share of F-gases by type in plant
Percentage by F-gases weight



- **R-407c**, a blend of hydrofluorocarbons (HFCs), is the **most used F-gases in EU chemical manufacturing plants**
- It accounts for **23% of all F-gases on average**, explained by its good performance, operational safe properties, and ability to be retrofitted into existing R-22 (HCFC-22) systems - *R22 was gradually phased out in the European Union starting in 2004*
- It is used in **cooling systems and heat pumps** for chemical processing and waste recovery, thanks to their stability, low flammability, and efficient heat transfer
- Typically, it represents **240kg of the total F-gases** used on average in a plant

R-407c is the most used F-gases in EU chemical manufacturing plants

Source: Accenture research, interviews and analysis

PFAS inventory

Results

19 – 35 kt

Fluoropolymer inventory (kt)

In use and in stock across equipment in EU chemical manufacturing plants

\+

4 kt

F-gases inventory (kt)

in use in EU chemical manufacturing plants

=

23 – 39 kt

Total PFAS Inventory (kt)

Total fluoropolymers and F-gases in use and in stock across the equipment in EU chemical manufacturing plants

Representing on average 1.8 – 3.0 t per plant

Based on **top-down** and **bottom-up** approaches

PFAS inventory is estimated between 23 and 39 kt across equipment in the EU chemical manufacturing plants

Table of Contents

PFAS alternatives & challenges

Executive summary (1/2)

Potential alternatives were assessed for each element across industrial equipment

- For each element containing PFAS, based on desk research and expert interviews, we have defined:
  - The **different PFAS substances** found
  - The **rationale** for using PFAS materials
  - The **identification of potential PFAS-free alternatives**
  - The **limitations and challenges** that hinder the implementation of potential alternatives

PFAS alternatives methodology

- Due to the combined thermal, chemical, and mechanical properties of fluoropolymers, **each potential alternative has been evaluated against each of these properties**:
  - **Thermal:** ability to withstand high and low temperatures without degrading, losing performance, or undergoing structural changes
  - **Chemical:** ability to resist corrosion, degradation, or reaction when exposed to aggressive chemicals (e.g., acids, bases, solvents, gases)
  - **Mechanical:** ability to endure mechanical stress, pressure, friction, and wear through strength, durability, and flexibility properties
- The potential alternatives evaluated include **polymers, metals and alloys, and other materials such as ceramics, glass, and graphite**, representing a total of **22 potential alternatives**
- The challenges of transitioning away from PFAS-free alternatives were assessed through 4 dimensions based on expert interviews: **alternatives development, value chain adaptation, HSE concerns and retrofitting**
- **An additional assessment** focused on how the Universal PFAS restriction proposal would differently impact **existing plants and new investments**

PFAS alternatives & challenges

Executive summary (2/2)

PFAS alternatives assessment results

- **Substituting fluoropolymers remains a complex challenge** due to their unique combination of thermal, chemical, and mechanical properties. While **individual alternatives** can match **specific characteristics**, none provide a comprehensive replacement. **3 categories of materials compete with fluoropolymers in diverging conditions:**
  - **Nickel alloy, Hastelloy (metals), ceramics and graphite (other materials)** offer stability across broad **temperature range**, though most of other alternatives perform less effectively under **cryogenic conditions**
  - **Nickel alloy, Hastelloy (metals) and glass (other materials)** match most of fluoropolymers' **chemical compatibility**, while other alternatives offer partial resistance but lack full-spectrum compatibility
  - **High-performance plastics** (PP, PET, HDPE, PEEK), provide strong **mechanical properties**, matching the fluoropolymers durability, robustness, elasticity, and wear resistance but to a large extent do not offer the same thermal resistance
- Given no material matches all key attributes, **substitution decisions must be based on specific process needs**

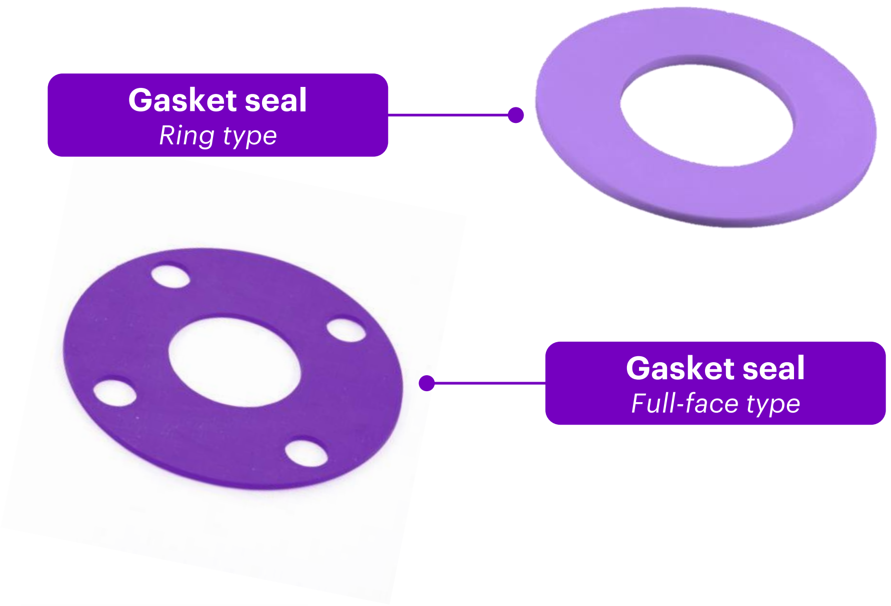
PFAS alternatives challenges

- Switching to PFAS-free alternatives involves significant **technical, industrial, and operational safety challenges**. Full transition depends on coordinated progress across multiple fronts:
  - **Alternatives development:** creating viable alternatives demands years of research, performance validation under real conditions, and alignment with recycling systems to support a circular economy
  - **Value chain adaptation:** as alternatives emerge, entire supply chain must evolve through securing raw materials, scaling production of niche materials and upgrading plant infrastructure for new material requirements
  - **HSE concerns:** without PFAS materials performance, operational safety risks like leaks or flammability may arise, while limited data on alternatives requires new standards and long-term risk monitoring
  - **Retrofitting:** Ensuring existing plants comply with new regulatory constraints through retrofitting will be a major challenge, as fluoropolymers are used in core industrial equipment such as reactors and piping. If feasible, such retrofits would require extended plant shutdowns beyond typical turnaround periods

PFAS alternatives & challenges

Components - Gaskets

Gaskets are made of PFAS for improved performance, mechanical and chemical resilience



PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • FEP • FFKM • **FKM – most common** • PCTFE • PFA • **PTFE – most common** • PVDF	• Provide resistance to temperature, and aggressive chemicals • Non-stick properties to reduce build-up and fouling	HDPE (for PTFE)	More friction, lower chemical and temperature tolerance
		Nickel	Less compatible with certain chemicals and more expensive
		Graphite	Brittle and can break under mechanical stress
		Mica	Less durable and not suited for dynamic uses
		Stainless steel	Not resistant to corrosion
		Synthetic rubbers (EPDM, NBR)	Worse chemical and temperature tolerance

Additional interviews insights

- **PTFE**, the most common PFAS material found in gaskets, accounts for up to **80% of fluoropolymer gaskets by volume** thanks to its combination of properties (resistant to heat, chemicals, and corrosion), performance, operational safety, and versatility
- Alternatives such as graphite can be cost efficient but the most pressing issues concern **hygiene, security, and environment** (HSE)
- Gaskets play an important structural role but have less stringent durability requirements than O-rings

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Components – O-rings (1/2)

PFAS improve the durability, chemical resistance, and performance of O-Rings seals in critical applications

O-ring seal

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • **FEP** – **most common** • FFKM • PCTFE • PFA • **PTFE** – **most common** • PVDF • TFE/P	• Provide resistance to temperature, and aggressive chemicals • Non-stick properties	HDPE (for PTFE)	More friction, worse chemical and temperature tolerance
		Nickel	Incompatible with certain chemicals and more expensive
		Graphite	Brittle and can break under mechanical stress
		Mica	Less durable and not suited for dynamic applications
		Synthetic rubbers (EPDM, NBR)	Worse chemical and temperature tolerance

Additional interviews insights

- **PTFE and FEP** are the most common PFAS materials found in O-Rings
- **PFAS are challenging to replace in O-rings**, as the need for **thermal and chemical resilience is critical**

PFAS alternatives & challenges

Components – O-rings (2/2)

PFAS improve the durability, chemical resistance, and performance of O-Rings seals in critical applications

Core

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• FKM	• Provide structural support to maintain O-ring shape • Improve flexibility and resilience	Silicone	Worse chemical and temperature tolerance and less durable Higher deformation after compression (compression set)
		Metals (steel)	Less flexible and less durable
		Synthetic rubbers (NBR)	Worse chemical and temperature tolerance and less durable

PFAS alternatives & challenges

Connectors – Expansion joints

Expansion joints use PFAS for their resilience and chemical resistance, preventing leaks between moving parts

Molded fluoropolymer bellows

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• FKM • PFA • **PTFE – most common**	• Provide resistance to temperature, erosion, and aggressive chemicals • Prevent gas and liquid leakages • Maintain connections across axial, angular, and lateral movements	Stainless steel	Less flexible and low corrosion resistance
		Synthetic rubbers (EPDM)	Worse chemical and temperature tolerance

Additional interviews insights

- **PTFE is the most common PFAS material in expansion joints** due to its ability to handle challenging chemical conditions
- Existing alternatives have drawbacks in terms of resilience and flexibility compared to fluoropolymer materials

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Connectors – Valves (1/2)

PFAS provide improved chemical and mechanical resistance and an extended service life to valve

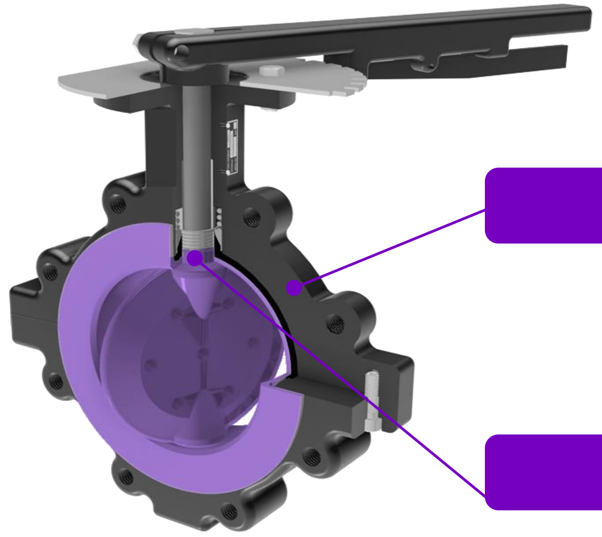


Illustration of a butterfly valve, contents of page also apply to ball, diaphragm, gate, globe, and check valve types

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • FEP • FKM • PFA • **PTFE – most common** • PVDF	• Resist aggressive chemicals • Reduce damage from erosion and abrasion	*Refer to lining*	*Refer to lining*
• FEP • FKM • PFA • **PTFE– most common**	• Resist aggressive chemicals • Reduce risk of leaks or failures due to high durability	*Refer to O-Rings*	*Refer to O-Rings*

Additional interviews insights

- Nearly all valves contain PFAS materials, with the **most common being PTFE**
- Most significant issues with PFAS-free alternatives in valves are related to **HSE standards, before cost and performance**

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Connectors – Valves (2/2)

PFAS provide improved chemical and mechanical resistance and an extended service life to valve

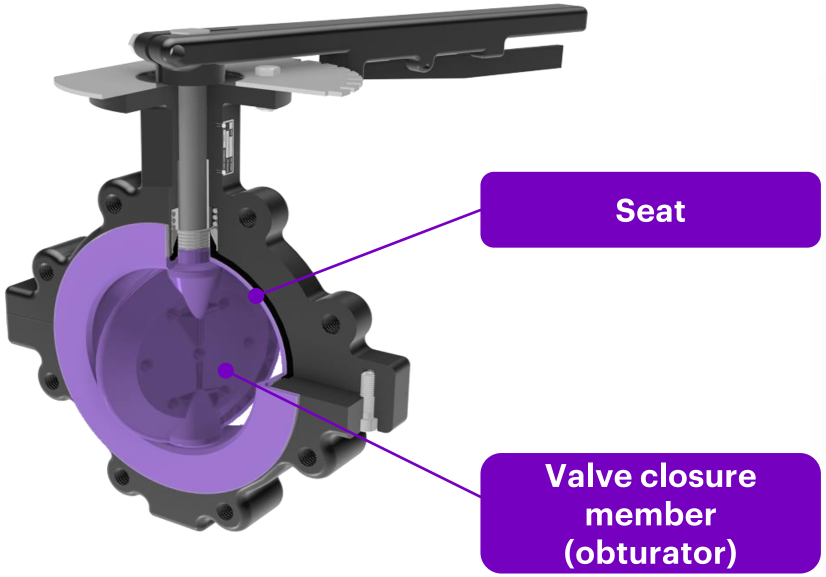


Illustration of a butterfly valve, contents of page also apply to ball, diaphragm, gate, globe, and check valve types

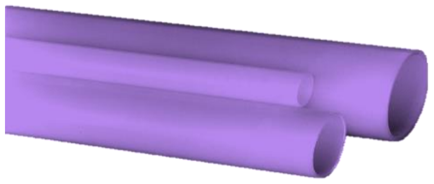
PFAS	Role of PFAS	Potential alternatives	Drawbacks
• FEP • FKM • PCTFE • PFA • **PTFE – most common**	• Resist aggressive chemicals • Reduce risk of leaks or failures due to high durability • Reduce damage from erosion and abrasion	PEEK	Worse chemical tolerance, significantly more expensive, and difficult to manufacture into precise shapes
		Carbon and graphite	Brittle, and can break under mechanical stress
		Vespel** (for PCTFE)	Significantly more expensive
• FEP • FKM • PFA • **PTFE – most common** • PVDF	• Resist aggressive chemicals • Reduce risk of leaks or failures due to high durability	Polyethylene	Worse chemical and temperature tolerance
		Stainless steel	Less flexible and low corrosion resistance

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Connectors – Pipes

Full-fluoropolymer pipes are used for their flexibility, chemical resistance, temperature resistance, and low friction



Pipe

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • FEP • **PFA** – most common • **PTFE** – most common • **PVDF** – most common	• Resist aggressive chemicals • Reduce risk of leaks or failures due to high durability	HDPE, Polyethylene	More friction, lower chemical and temperature tolerance
		Polypropylene and PVC	Worse thermal and chemical tolerance and not suitable for highly demanding applications* unless reinforced
		Hastelloy	More expensive and four times heavier than PTFE, requiring changes in design
		Stainless steel, Copper, Nickel, Titanium	Less flexible, less insulation properties, less resistance to corrosion, increase weight and size of components

Additional interviews insights

- **Polypropylene** is increasingly used as a replacement for fluoropolymer materials in pipes, where applicable

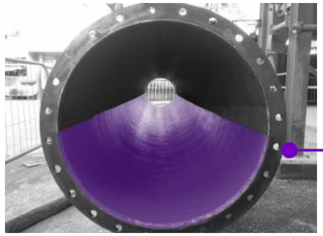
Note: *Applications involving high pressure, high temperature and exposure to aggressive chemicals
Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Lining

Fluoropolymers in lining act as a protective barrier within the chemical production process

Pipe lining



Vessel lining

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • FEP • PFA • **PTFE – most common** • **PVDF – most common**	• Resist aggressive chemicals • Stay stable across a broad temperature range • Increase the lifespan of the equipment it is applied to	Ceramic, glass	Brittle, can break under mechanical stress. Glass is incompatible with hydrofluoric acid
		PEEK	Worse chemical tolerance, significantly more expensive, and difficult to manufacture into precise shapes
		HDPE, polyurethane, polypropylene	Unsuitable for high temperature applications and harsh chemicals

Additional interviews insights

- **PEEK** is a promising alternative for pipe lining, though its complex manufacturing and high costs pose significant challenges
- **Glass lining** in reactors have comparable performance and superior longevity to fluoropolymers, but higher costs and are incompatible with hydrofluoric acid

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Coating

Coatings are of 3 types: powder, solvent-based and water-based. PFAS are used for metal surface coating in pipes, reactors, vessels and storage tanks

Coating

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • ETFE • FEP • FEVE • **PFA – most common** • **PTFE – most common** • **PVDF – most common**	• Stay stable across a broad temperature range • Non-flammable • Provide corrosion, UV and weathering protection	Epoxy powder	Need flame retardants to be flame resistant and leaches bisphenol A at 50-200°C
		PVC and polyester based coatings	Worse temperature and chemical tolerance
		Polyurethane, HDPE and polystyrene-based coatings	Worse temperature and corrosion resistance, need flame retardants to be flame resistant

Additional interviews insights

- Coatings are primarily used for **corrosion resistance**, therefore, fluoropolymer-based options are generally not required when chemical and thermal resistance are not critical
- In less demanding applications, the **main limitation of alternatives is the lower durability**, resulting in the need of more frequent reapplication
- When coatings contain fluoropolymers, it is in **low amounts** as coating is typically less than 1mm thick

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Lubricants (1/2)

Lubricants consist of a base oil, thickeners, and additives all of which may include PFAS

Base oil
70-90 weight %

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• PCTFE oil • **PFPE oil** – **most common**	• Provide chemical inertness • Stay stable across a broad temperature range • Non-flammable • Suitable for vacuum applications • Chemical compatibility with polymers	Silicone oil (only for PFPE oil)	• Limited temperature resistance • Lower durability • Not suitable for controlled environment (e.g., for microchips)

Additional interviews insights

- Research is currently ongoing to **develop equipment that operates without lubricants**, however, this affects the design of certain parts and may reduce their lifespan
- Based on expert insights, on overall applications, **<10%** can be covered by alternatives without significant performance losses, **30%** with significant performance losses, **60%** would suffer critical performance losses

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Lubricants (2/2)

Lubricants consist of a base oil, thickeners, and additives all of which may include PFAS

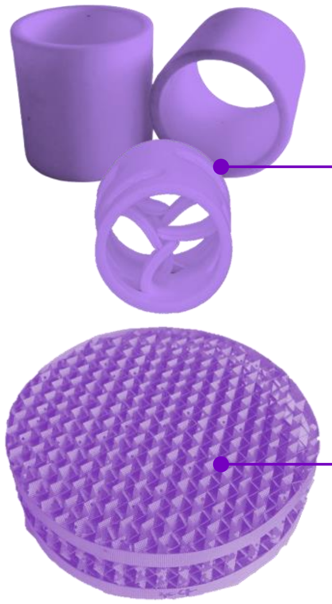
	PFAS	Role of PFAS	Potential alternatives	Drawbacks
Thickeners *2-20 weight %*	• PCTFE • PTFE	• Resist aggressive chemicals • Stay stable across a broad temperature range • Chemical compatibility with polymers	Lithium salts	Not compatible with PFPE oil
			Graphite, MoS_2, boron nitride	No drawbacks identified
Additives *2-10 weight %*	• PTFE	• Reduce wear due to low coefficients of friction • Enhance longevity of mechanical components • Chemical compatibility with polymers	Graphite, MoS_2, boron nitride, silicone-based additives	No drawbacks identified

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Column packing

Column packing can be made of PFAS materials to handle corrosive chemicals



Random packing

Structured packing

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • **PFA – most common** • **PTFE – most common** • **PVDF– most common**	• Increased longevity and efficiency • Non-stick properties to reduce fouling • Corrosion resistance	PEEK	Significantly more expensive, and difficult to manufacture into precise shapes
		Stainless steel	Not resistant to corrosion and less durable
		Ceramics, graphite, carbon	Brittle materials which can break under mechanical stress

Additional interviews insights

- **PFAS column packing represents a very small fraction (less than 5%) of the usage in a plant**, with stainless steel being the predominant material
- Replacement usually occurs during plant turnarounds or due to performance degradation

Source: Accenture research, interviews and analysis

Membranes use fluoropolymers for improved longevity and resilience to mechanical and chemical damage

Membranes separate, filter, or concentrate substances for process operations

Membrane

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• FEP • FKM • PCTFE • PFA • **PTFE** – most common • **PVDF** – most common	• Resistance to erosion and abrasion • Chemical resilience in harsh environments • Reduce operational safety related risks	PES (for PVDF)	Chemical and temperature tolerance Incompatible with high intensity processes
		CPVC	More prone to fouling Incompatible with high intensity processes

Additional interviews insights

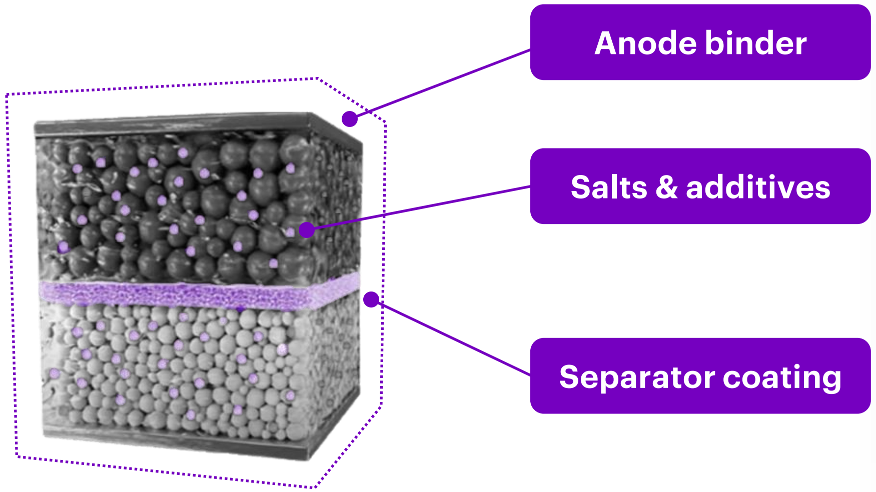
- **No viable alternatives to PFAS membranes** are currently available for **critical applications where operational safety , high performance** and **extreme durability** are required

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Battery (1/2)

Lithium-ion batteries in chemical manufacturing plants are mainly used for backup power, mobile equipment, and portable monitoring devices



PFAS	Role of PFAS	Potential alternatives	Drawbacks
• PVDF (minor)	Provide electrochemical, chemical and thermal stability and adhesion properties	SBR/CMC (water-based binders)	None identified, already replace PVDF
• LiBETI • LiTFSI • Li-triflate	Improve performance, durability, and operational safety	$LiPF_6$, $LiBF_4$, $LiClO_4$	Lower durability
• PVDF	Provide electrochemical, chemical and thermal stability and wettability properties	Polyethylene, polypropylene	Less thermal stability and poor wettability with electrolytes
		PET	Less electrochemically stable at high voltage and higher rigidity

Additional interviews insights

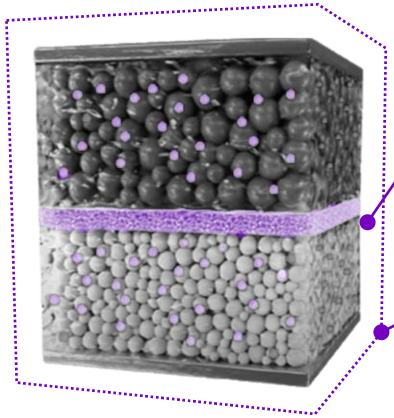
- **Lead-acid batteries** are potential replacement to lithium-ion batteries in chemical plant applications
- Initiatives are being implemented to **optimize battery recycling** processes (**pyrometallurgy** process)
- Companies are developing new binders' materials to **reduce the amount of binder needed**

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Battery (2/2)

Lithium-ion batteries in chemical manufacturing plants are mainly used for backup power, mobile equipment, and portable monitoring devices



	PFAS	Role of PFAS	Potential alternatives	Drawbacks
Cathode binder	• PTFE • PVDF	• Provide electrochemical, chemical and thermal stability and adhesion properties	SBR/CMC (water-based binders)	Reduce performance because cathodes require non-aqueous processing and less resistant to high voltage
Cell gasket	• PFA • FEP • FKM • PTFE	• Provide resistance to aggressive chemicals • Hydrophobic properties • Improve operational safety due to high durability	*Refer to gaskets*	*Refer to gaskets*

Additional interviews insights

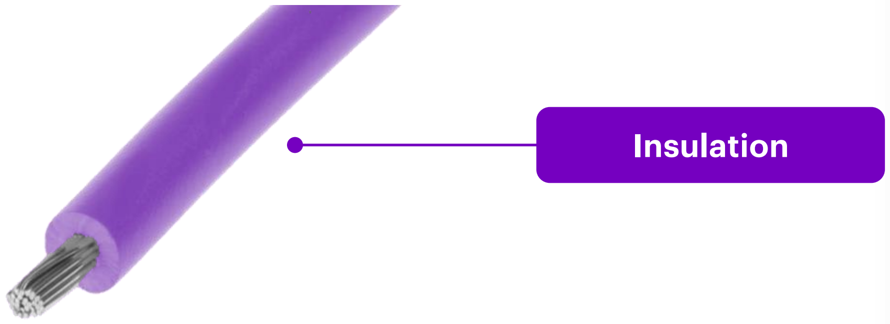
- **Lead-acid batteries** are potential replacement to lithium-ion batteries in chemical plant applications
- Initiatives are being implemented to **optimize battery recycling** processes (**pyrometallurgy** process)
- Companies are developing new binders' materials to **reduce the amount of binder needed**

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Other equipment – Electric wires

PFAS materials serve as insulators in electric wires for their dielectric and flexibility properties



PFAS	Role of PFAS	Potential alternatives	Drawbacks
• ECTFE • **ETFE** – most common • **FEP** – most common • FFKM • FKM • MFA • PCTFE • PFA • **PTFE** – most common • PVDF	• Provide thermal stability and fire safety • Flexibility • Chemical resistance • Low coefficient of friction • Electric insulator	Polyethylene, polypropylene, PVC, XLPE, SBR, NBR	Less thermal stability through wide temperature range and less chemical resistant
		Silicone	Worse temperature and chemical resistance
		Polyimide, PEEK, fiberglass	Less flexible, not easy to process

Additional interviews insights

- **PFAS** are used when **combination of several properties** (flexibility, resistance to UV, high temperature, low friction) **is required**
- **Silicone** is a suitable alternative for many applications (except harsh chemicals) but is also subject to regulations in the EU

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Other equipment - Circuit breakers

PFAS are used in lubricants of circuit breakers, to reduce friction and ensure long-term reliability

Lubricant

PFAS	Role of PFAS	Potential alternatives	Drawbacks
• PTFE	• Low coefficient of friction • Stable across a broad temperature range • Long-term durability • Low surface tension for dielectric products	Silicone-based lubricants	• Limited temperature resistance • Lower durability especially in humid or dusty conditions

Additional interviews insights

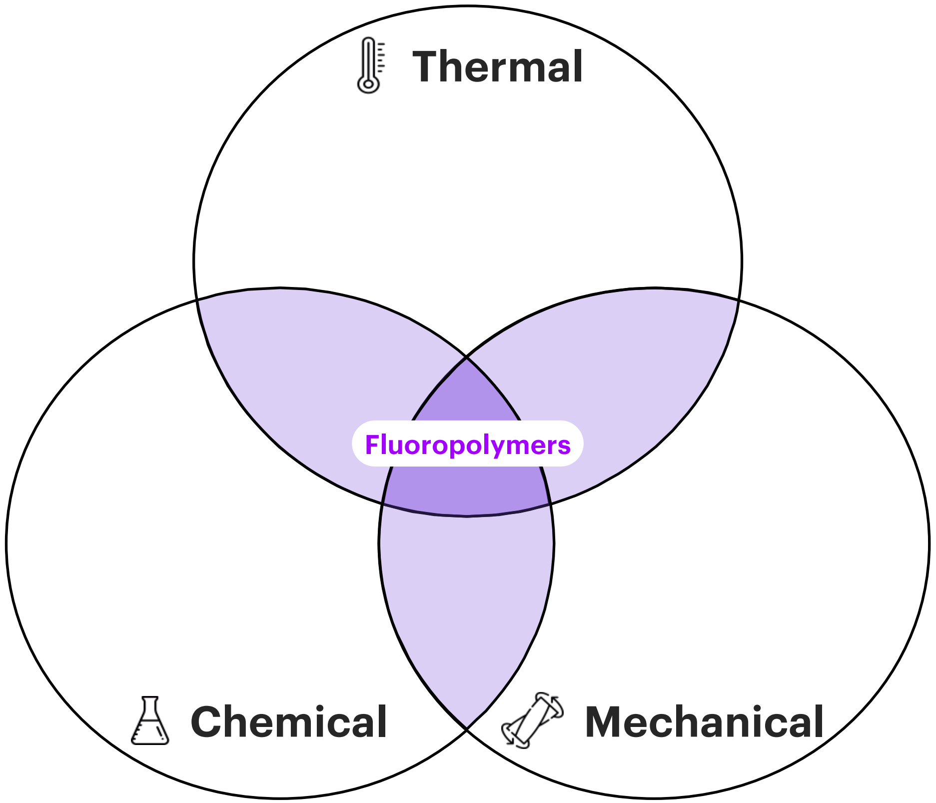
- **Redesign circuit breakers** to reduce friction may enable use of fluoropolymer-free alternative materials, but would require significant engineering adjustments
- Purely **electrical circuit breakers** (no requiring lubrication), could serve as an alternative but are currently not permitted in Europe
- Transition to PFAS-free solutions is possible but will require significant time, **5 to 10-year timeline** depending on regulatory developments

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Methodology

Due to the combined thermal, chemical, and mechanical properties of fluoropolymers, **each potential alternative will be evaluated against each of these properties**



Thermal: ability to withstand high and low temperatures without degrading, losing performance, or undergoing structural changes

Chemical: ability to resist corrosion, degradation, or reaction when exposed to aggressive chemicals (e.g., acids, bases, solvents, gases)

Mechanical: ability to endure mechanical stress, pressure, friction, and wear through strength, durability, and flexibility properties

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives evaluated

Polymers

Plastics

- Polyolefins: High-density polyethylene (HDPE), Low-density polyethylene (LDPE), Polypropylene (PP)
- Polyvinyl chloride (PVC)
- Polyethylene (PET)
- Polyurethane (PU) / Polystyrene (PS)
- Epoxy
- Polyimide
- Polyether ether ketone (PEEK)

Elastomers

- Synthetic rubbers: Styrene butadiene rubber (SBR), Nitrile butadiene rubber (NBR), Ethylene propylene diene monomer (EPDM)
- Silicone (solid and oil)

Metals & alloys

- Stainless steel
- Nickel alloy
- Copper
- Titanium
- Hastelloy

Other materials

- Ceramic
- Glass
- Graphite

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives – Thermal property (1/2)

PFAS

Fluoropolymers

- Fluoropolymers possess desirable thermal resistance properties, making them suitable for a wide range of processes
- PTFE and PFA (perfluoroalkoxy) possess the widest range of thermal properties, withstanding temperatures from -**260°C to -260 °C** in operational conditions

Potential alternatives

Polymers

- Polymeric alternatives **fail to match temperature resistances of fluoropolymers** especially in cryogenic temperatures
- The most promising high-temperature alternatives are **PEEK** and **silicone** (both solid and oil), which can withstand temperatures up to **250°C**
- For low-temperature applications, **HDPE, LDPE** and **silicone oil** perform best, operating at **-70°C** and **-90°C**, respectively

Metals & alloys

- **Metals & alloys have higher range resistance** in high temperature, but often lack resistance to cryogenic temperatures
- **Hastelloy** and **nickel alloys** match the temperature range of fluoropolymers and even **exceed their performance at high temperatures**, operating up to **700°C** and **1000°C**

Other materials

- **Ceramic and graphite offer better thermal resistance** than fluoropolymers, operating up to **1600°C for ceramic**
- These materials involve **higher costs** and more complex processing methods

Potential alternatives

- **Hastelloy** – *Metal & alloys*
- **Nickel alloy** – *Metal & alloys*
- **Ceramic** – *Other materials*
- **Graphite** – *Other materials*

Hastelloy, nickel alloy, ceramic and graphite match fluoropolymers' stability across a broad temperature range

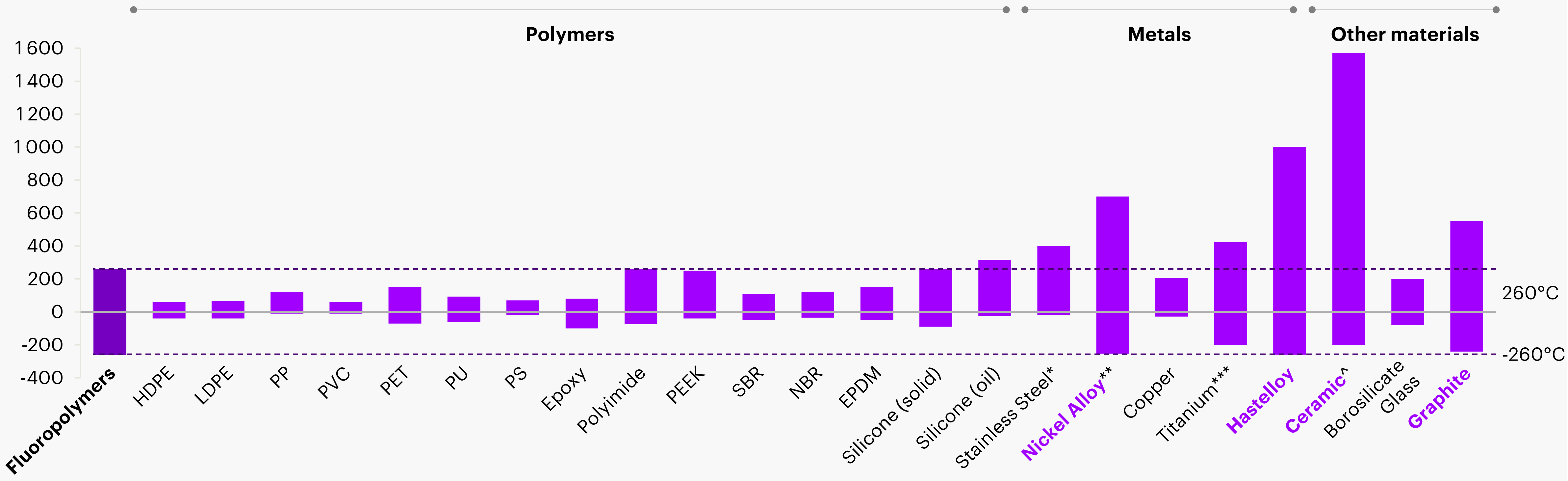
Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives – Thermal property (2/2)

Range of thermal resistance of alternatives

Operating temperatures
Temperature (°C)



Note: *AISI 316Ti, **INCONEL 718, ***Titanium Grade 2, ^Silicon Carbide
Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives – Chemical property (1/2)

PFAS

Potential alternatives

Fluoropolymers

- The majority of fluoropolymers, except FKM, are **chemically compatible with all substance families**: acids (strong and weak), bases (strong and weak), oxidizers and solvents (polar and non-polar)

Polymers

- **Polymers offer little to no chemical compatibility with most substance families**
- **Polyimide** is the only suitable option compatible with all chemicals*
- **Plastics** generally **lack resistance to solvents** and have limited compatibility with **acids**
- **Elastomers show almost no chemical resistance** across all substance families

Metals & alloys

- **Metals and alloys exhibit chemical resistance comparable to fluoropolymers** but with reduced compatibility to acids as they are usually **prone to corrosion**
- **Hastelloy** provides broad chemical compatibility across **all substance** families
- **Nickel alloys** offer extensive resistance, with only limited compatibility with **strong acids**

Other materials

- **Ceramic and glass offer satisfying chemical resistance** but have lower compatibility with strong acids and oxidizers
- **Graphite** also exhibits broad chemical compatibility, but is not compatible with strong acids and oxidizers

Potential alternatives

- **Hastelloy** – *Metals & alloys*
- **Nickel alloy** – *Metals & alloys*
- **Glass** – *Other materials*
- **Polyimide** – *Polymers*
- **Ceramic** – *Other materials*

Alternatives from all categories perform well with specific chemicals but lack resistance to a broader range of substances

Note: *Except KOH
Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives – Chemical property (2/2)

Family substances	Fluoropolymers	Polymers	Metals & alloys	Other materials (incl. ceramic, glass, graphite)
Acids (strong & weak)	Strong	Low	Low	Medium
Bases (strong & weak)	Strong	Medium	Medium	Strong
Oxidizers & reactive chemicals	Strong	Low	Medium	Medium
Solvents (polar & non-polar)	Strong	Low	Strong	Strong

Polymers exhibit **low to moderate chemical compatibility**, struggling with acids and oxidizers while showing limited resistance to solvents

Metals & alloys offer **moderate chemical resistance**, handling solvents but showing variability in compatibility with acids and oxidizers

Other materials display satisfying chemical resistance, nearly comparable to fluoropolymers, making them suitable for wide range of chemical substances

Other materials – glass, ceramic, and graphite - exhibit strong chemical resistance, closely matching fluoropolymers

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives – Mechanical property (1/2)

PFAS

Fluoropolymers

- Fluoropolymers provide a **balance of strength, flexibility, and durability**, making them well-suited for demanding mechanical applications
- **ECTFE** stands out as the most rigid, offering the highest resistance to deformation

Potential alternatives

Polymers

- **Polymers offer moderate mechanical resistance** through different constraints
- **HDPE, PP, PET and PEEK** represent suitable alternatives, covering the same mechanical profile as PFAS except for wear resistance
- **Silicone** is also a suitable alternative, but lacks some robustness compared to PFAS
- **Elastomers** have interesting properties for applications where high flexibility is required

Metals & alloys

- Metals and alloys offer **high robustness and rigidity**, but have low elasticity and are prone to brittleness under tension
- **Hastelloy stands out** for its superior durability and resistance to mechanical stress in demanding conditions, but its heavier weight is a drawback

Other materials

- Ceramics, glass, and graphite provide **high stiffness and compressive strength** but have **no elasticity**
- Despite their resistance, these materials are not suitable for applications requiring flexibility as they are subject to brittleness and surface etching

Potential alternatives

- **HDPE** – *Plastics/Polymers*
- **PP** – *Plastics/Polymers*
- **PET** – *Plastics/Polymers*
- **PEEK** – *Plastics/Polymers*
- **Silicone** – *Elastomers/Polymers*

High-performance plastics can match fluoropolymers' balance of mechanical properties

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives – Mechanical property (2/2)

Mechanical properties	Fluoropolymers	Polymers	Metals & alloys	Other materials (incl. ceramic, glass, graphite)
Tensile strength (fragile/robust)	Low/Medium robustness	Low/Medium robustness	Strong robustness	Medium robustness
Young's modulus (soft/rigid)	Medium/Strong rigidity	Medium/ Strong rigidity	Strong rigidity	Strong rigidity
Elongation (brittle/elastic)	Strong elasticity	Strong elasticity	Low elasticity	Low elasticity
Friction (erosive/wear-resistant)	Medium wear-resistance	Low/Medium wear-resistance	Strong wear-resistance	Strong wear-resistance

Polymers typically exhibit **moderate mechanical resistance**, with a wide range of elasticity depending on their composition, with elastomers being the most flexible

Metals & alloys offer **high mechanical resistance**, with high stiffness and tensile strength, but also exhibit low elongation, making them prone to brittleness

Other materials offer high stiffness and compressive strength but are extremely brittle, making them prone to fracture under tension

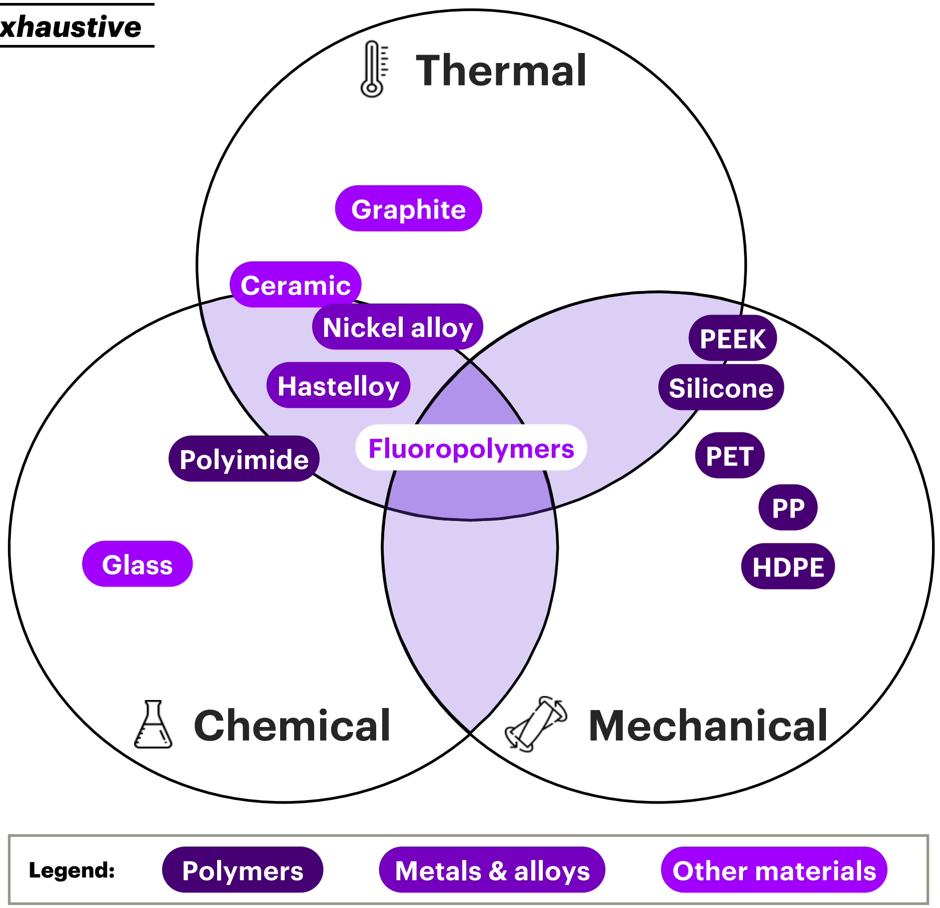
Polymers offer flexible and durable mechanical profile, close to fluoropolymers properties

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Potential alternatives – Results

Non-Exhaustive



- **No alternative succeeds** in replicating all 3 key properties of fluoropolymers
- **Nickel alloy, Hastelloy (metals), ceramics and graphite (other materials)** offer stability across broad **temperature** range, though most of other alternatives perform less effectively under **cryogenic conditions**
- **Hastelloy, nickel alloy (metals) and glass (other materials)** match fluoropolymers' **chemical** compatibility, while other alternatives offer partial resistance but lack full-spectrum compatibility
- **High-performance plastics** (PP, PET, HDPE, PEEK), part of polymers, provide strong **mechanical** properties, matching the fluoropolymers durability, robustness, elasticity, and wear resistance
- **Reassessment based on specific needs and operating conditions** will be necessary to evaluate possible alternatives on a case-by-case

Thermal: ability to withstand high and low temperatures without degrading, losing performance, or undergoing structural changes

Chemical: ability to resist corrosion, degradation, or reaction when exposed to aggressive chemicals (e.g., acids, bases, solvents, gases)

Mechanical: ability to endure mechanical stress, pressure, friction, and wear through strength, durability, and flexibility properties

Replacing fluoropolymers is challenging, as alternatives rarely match their combined properties

Note: Not all parameters are accounted for in this representation, as it is meant to provide a general visual overview
Full details can be found in the following slides of the report
Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Summary of survey results

	If you **have identified alternatives** for PFAS-containing components, what **limitations**, if any, do they have?	If you **have not identified an alternative** for PFAS-containing elements, could you please explain **the reasons why**?
Performance	• Possible alternatives generally show **lower chemical** and **temperature** resistance, **mechanical** properties, and shorter **lifespan** • **Lubricants**: alternatives often use toxic additives to match PFAS performances	• Alternatives lack the same **chemical** resistance, **temperature** tolerance, **mechanical strength/flexibility** and **lifespan as PFAS** • Most equipment is supplied by **external suppliers**, requiring their **approval** before any material changes can be made • Some PFAS-containing products (e.g., membranes) **lack alternatives**, even with lower performance
HSE	• **Risk of leakage**, particularly with hazardous chemicals, and corrosion concerns will affect personnel, processes, and environment • Increased maintenance intervals will **raise worker exposure** to potential accidents	
Costs	• Alternatives will require **more spare parts management**, increasing maintenance and replacement costs	
Others	• Alternatives often require **redesigning equipment**: different piping classes and weight distribution, new gaskets sizes, heavier column packing with ceramics alternatives • PFAS-free alternatives fail to cover the full range of conditions PFAS meet, **reducing standardization** and requiring case-specific solutions	• **Compatibility** with equipment, processes, and OEM specifications is essential for optimal performance and **will need to be reassessed** • **Lubricants:** equipment designed for PFAS lubricants depends on their performance for reliability and maintenance schedules, which will need adjustment with alternatives

The study highlights that finding suitable alternatives is challenging due to performance gaps, operational safety concerns, and the need for significant equipment redesign

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Reflections on transitioning from PFAS to viable alternatives

During the expert interviews, various points were raised, focusing not only on the identification of viable alternatives but also on the **broader considerations surrounding the transition toward their implementation**

1 Alternatives development

- Extensive **R&D, testing and regulatory approvals** are needed to validate performance under operating conditions for chemical manufacturing plants
- Regarding competitors out of Europe, **alternatives must be cost-competitive** for EU manufacturing companies while offering durability and efficiency comparable to PFAS
- Infrastructure is needed to recycle and collect new materials alternatives and integrate them within a **circular economy model**

2 Value chain adaptation

- **Some alternatives are limited to niche markets,** with only few producers, which could lead to supply bottlenecks. Scaling up production requires constructing new facilities from the ground up
- **Raw material sourcing** may face similar constraints, requiring supply chain adjustments and diversification strategies
- Existing chemical manufacturing plants will need **infrastructure modifications**, such as redesigned machinery to accommodate new material properties

3 HSE concerns for future installations

- **Performance and durability gaps** compared to PFAS could introduce **safety hazards** like leakage, flammability, or toxicity
- **Limited long-term data** on new alternatives raises uncertainty about potential HSE risks, requiring extensive monitoring and risk assessment
- Alternatives will require adapting or **redefining industry standards** to ensure compliance and operational safety

4 Retrofitting

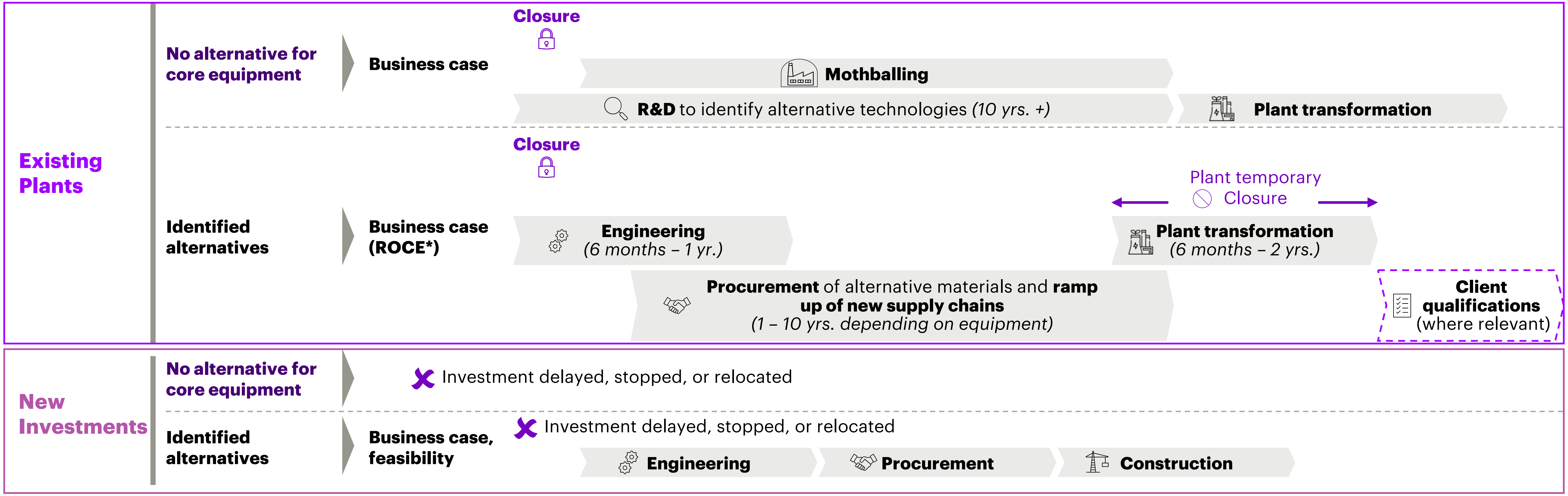
- Potential PFAS restriction would directly impact existing facilities, **requiring plant retrofitting in order to meet new regulatory constraints**
- Substitution will pose **major technical and operational constraints** leading to retrofitting, especially in complex, integrated process environments
- In some cases, extensive retrofitting may **require partial shutdowns** or **mothballing,** leading to **costly disruptions** and **downtime**

Source: Accenture research, interviews and analysis

PFAS alternatives & challenges

Impact on existing plants and new investments

Impact of a potential restriction on PFAS in new equipment will depend on the extent and duration of potential derogations



Substitution will pose significant constraints for retrofitting existing plants, potentially requiring extensive mothballing

Note: *Return On Capital Employed
Source: Accenture research, interviews and analysis

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Restriction on PFAS would have a major impact on the chemical manufacturing industry (1/3)

Economic impact of pending Universal PFAS restriction under REACH methodology

- **A section of the survey focused on the economic and socio-economic impacts on EU chemical manufacturing companies of pending Universal PFAS restriction under REACH** was developed and completed by Cefic members. It included **three scenarios** :
  - **Scenario 1: Restriction on PFAS takes place in 2029** after which it is impossible to obtain new equipment containing PFAS materials, but equipment already in use and in stock in European chemical manufacturing plants can be used until replacements are needed
  - **Scenario 2: Restriction takes place in 2041** instead, while rest of the parameters remain identical to first scenario
  - **Scenario 3: Derogation without time-limit** is granted, under condition that a **detailed substitution and emission reduction plan is implemented as of 2029**
- **Quantitative and qualitative answers** were collected and analysed by Accenture
- Topics included in the survey:
  - **Value chain impact** (affected value chain, upstream, downstream)
  - **Impact on key business metrics** (Portfolio, turnover, Gross value added (GVA))
  - **Impacts on operating costs** (OPEX, Maintenance, Downtime)
  - **Capital costs** (CAPEX, R&D)
  - **Socio-economic costs** related to impacts on direct and indirect employment (refers to jobs external to companies, such as subcontractors, suppliers, or local businesses close to the plant)
  - **Costs related to PFAS handling** (monitoring and reporting, emission reduction, PFAS management costs)

Restriction on PFAS would have a major impact on the chemical manufacturing industry (2/3)

Economic impact results

- **The chemical manufacturing sector is characterized by capital intensity, inflexible production assets, and long investment cycles.** Uncertainty is a critical challenge, as significant investments are required for future changes, making **clarity essential to ensure informed decision-making and effective allocation of resources**
- **Any new regulations would have both economic and socio-economic impacts on EU chemical manufacturing companies**

Focus on value chain

- Across all scenarios, **PFAS restrictions would severely affect the chemical manufacturing value chain**, with even companies less dependent on PFAS-containing equipment experiencing disruptions due to upstream impacts. The severity of impact varies by scenario: **Scenario 1 shows the highest impact (75%), Scenario 2 results in widespread operational disruptions despite an extended deadline**, and **Scenario 3 sees comparatively lower effects (46%)** due to derogations limiting shutdowns and efficiency losses

Focus on portfolio, turnover and GVA

- Across all scenarios, **companies' portfolios would be strongly affected**, leading to losses in both turnover and gross value added. **Scenario 1 shows the greatest impact at 73%** due to a lack of alternatives and high costs placing companies at risk of shutdown or relocation**. Scenario 2 offers only slight relief, with a 63% impact despite the extended deadline**. **Scenario 3 results in milder effects, with a decline of 46%**

Focus on operating and capital costs

- **Operating costs** (including maintenance and downtime) **could rise by 59% based on current baseline under Scenario 1, 56% for scenario 2 and 31% under Scenario 3.** Replacing fluoropolymers elements in equipment leads to higher frequency of maintenance, repairs, and replacements, as alternatives are less resilient, thus increasing operational expenses
- **Companies anticipate significant rises in CAPEX in scenarios involving PFAS restrictions (scenario 1 and 2)**, as plants undergo significant transformations comparable to complete rebuilds. **Capital expenditures to retrofit plant would increase by 59% based on current baseline in Scenario 1, 52% in scenario 2 and 29% in Scenario 3**

Restriction on PFAS would have a major impact on the chemical manufacturing industry (3/3)

Focus on direct and indirect employment

- Socio-economic impacts include employment losses and restructuring. **Most companies expect reductions in direct (64% and 61% respectively in scenario 1 and 2) and indirect employment (65% and 59% in scenario 1 and 2)** due to revenue loss, site closures, or relocations
- In Scenario 3, **a smaller impact on direct (31%) and indirect (32%) employment** is expected, as the increased need for employees in monitoring and reporting may help offset some of the job losses resulting from reduced productivity

Focus on costs related to PFAS handling

- **All scenarios involve cost increases tied to PFAS monitoring, management, and emissions reduction**, estimated between 30% and 45% above the current OPEX baseline. New organizational structures would likely be required to manage these functions

Context

EU Chemical manufacturing industry key figures

Key figures
(2023)

655 Bn€
sales (13% of the global chemical industry revenues)

50 Bn€
In investments representing the largest investor in EU manufacturing sector

Innovation and R&I*
(2023)

32 Bn€
capital spending (12% of the global chemical industry)

10 Bn€
R&I spending (18% of the global share)

Employment
(2023)

3.4 M
direct employees

Up to 10 M
indirect employees, including suppliers (e.g., maintenance, equipment, transports, logistics)

Environmental leadership
(2023)

-60%
GHG emissions since 1990 in 2022

13%
total feedstock coming from recycled content

Contribution to decarbonization of downstream industries through innovation

PFAS economic impact

Industrial realities of the Chemical manufacturing sector

Capital intensive

Building chemical manufacturing plant **takes several years** and **requires investments** from **hundreds of millions** to **several billion euros**

Strong integration and value chains

Upstream and downstream operations are **tightly linked**, meaning any **disruptions can impact entire value chains**

Inflexible production assets

Plants are specialized for specific chemical productions, making repurposing costly and challenging

Regulations and safety constraints

European chemical manufacturing industry follows **strict safety, health, and environmental regulations**

Long asset lifetime

Plants are built to **operate for decades**, sometimes **more than 40 years**, resulting in **expensive and slow technological and environmental retrofits**

Global competitiveness

A Globally competitive industry under high-cost pressures, where small changes in costs and production efficiency can **reduce competitive advantages**

Chemical manufacturing sector is shaped by capital intensity, inflexible production assets, and long investment cycles

Source: Accenture research, interviews and analysis

PFAS economic impact

Challenges to strategic flexibility

Expensive and lengthy investments limit adaptability

- Construction of plants costs range from **hundreds of millions** to **several billion euros and takes 5 to 10 years**
- Assets are expected to operate between **30 to 40 years**

Companies need clarity over future market changes

Companies need to anticipate:

- **Evolution of future demand**
- **Changes in regulatory frameworks**
- **Feedstock availability**
- **Future technologies**

High uncertainty leads to negative outcomes

- Major **investments are delayed or cancelled**
- Existing **processes are maintained** over potentially more efficient and sustainable ones
- **Investments in R&D become limited** due to unclear returns

Uncertainty is a critical issue in the chemical manufacturing industry

Source: Accenture research, interviews and analysis

PFAS economic impact

Parameters considered to assess potential impacts arising from new regulations

Value chain
- Affected value chain
- Upstream
- Downstream

Key business metrics
- Portfolio
- Turnover
- GVA (Gross Value Added)

Operating costs
- OPEX
- Maintenance
- Downtime

Capital costs
- CAPEX
- R&D

Socio-economic costs
- Direct employment
- Indirect employment*

Any new regulations would have both economic and socio-economic impacts on chemical manufacturing plants in Europe

Note: *Refers to jobs external to companies, such as subcontractors, suppliers, or local businesses close to the plant
Source: Accenture research, interviews and analysis

PFAS economic impact

Scenarios

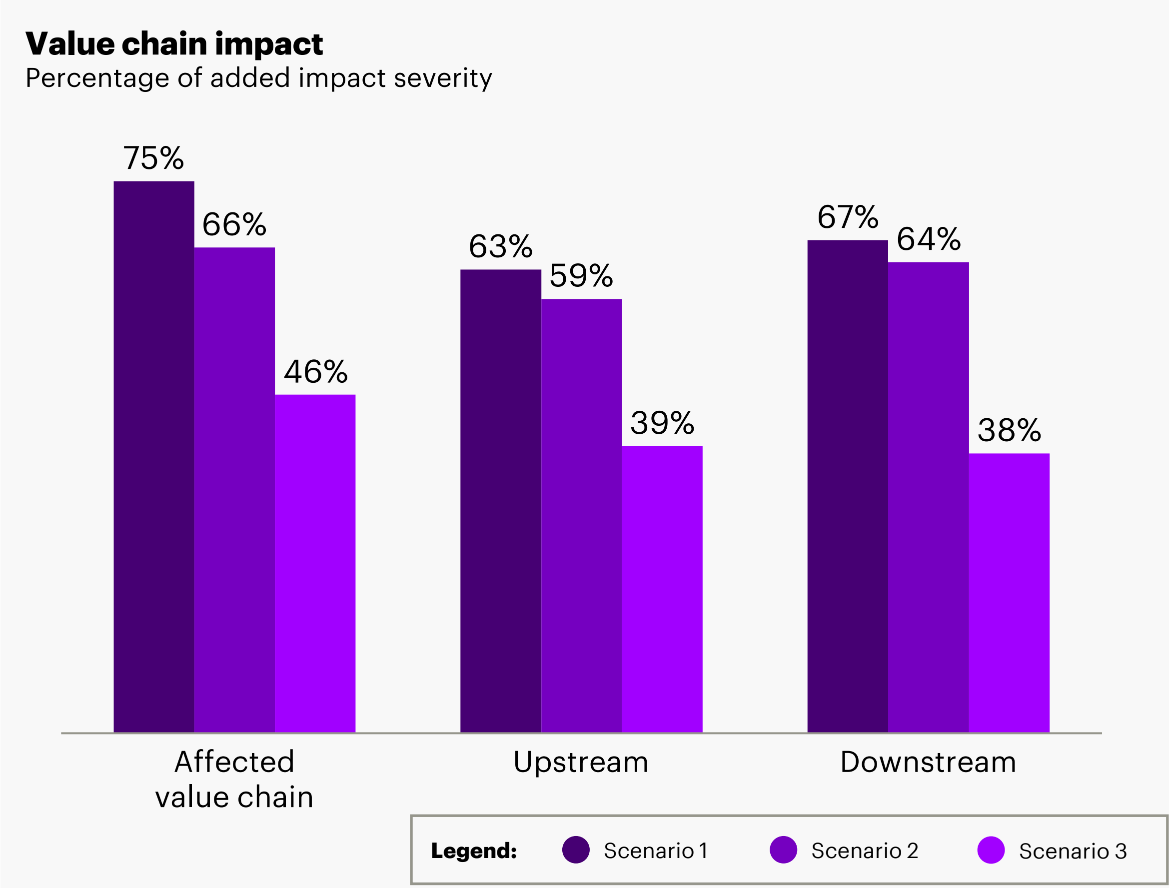
Potential economic impact of PFAS restrictions is assessed through three possible scenarios

Scenario 1	Restriction on PFAS, **effective from 2029**, impact industrial equipment and components across various industries, including chemical manufacturing. Although **chemical manufacturing companies may continue to operate** their facilities using **existing and in stock** PFAS-containing equipment and components, **any replacements made after 2029 must use PFAS-free alternatives**
Scenario 2	Restriction on PFAS, **effective from 2041**, impact industrial equipment and components across various industries, including chemical manufacturing. Although **chemical manufacturing companies may continue to operate** their facilities using **existing and in stock** PFAS-containing equipment and components, **any replacements made after 2041 must use PFAS-free alternatives**
Scenario 3	European chemical manufacturing industry granted **derogation without time-limit**, under condition that **detailed substitution and emission reduction plan is implemented as of 2029**. This includes cost of managing PFAS, such as monitoring, reporting, substitution efforts, and emission reduction measures

Source: Accenture research, interviews and analysis

PFAS economic impact

Value Chain Impact



- **Across all scenarios** restrictions would have severe impacts throughout the chemical manufacturing value chain. Companies less reliant on equipment with PFAS would still be impacted if their **upstream suppliers were impacted**
- **Scenario 1:** The strongest impacts would be felt under this scenario, with companies **rating the impact on their value chain at 75%**
- **Scenario 2:** Operations remain severely impacted, leading to all around disruptions. **Few respondents considered the extended deadline sufficient to mitigate effects**
- **Scenario 3:** The derogation would lead to comparatively **fewer shutdowns and efficiency losses**, explaining the **lessened impacts on the value chain (46%)**

"... The entire chemical manufacturing chain would be affected [...] our feedstock suppliers would face the same problems as us and downstream also"

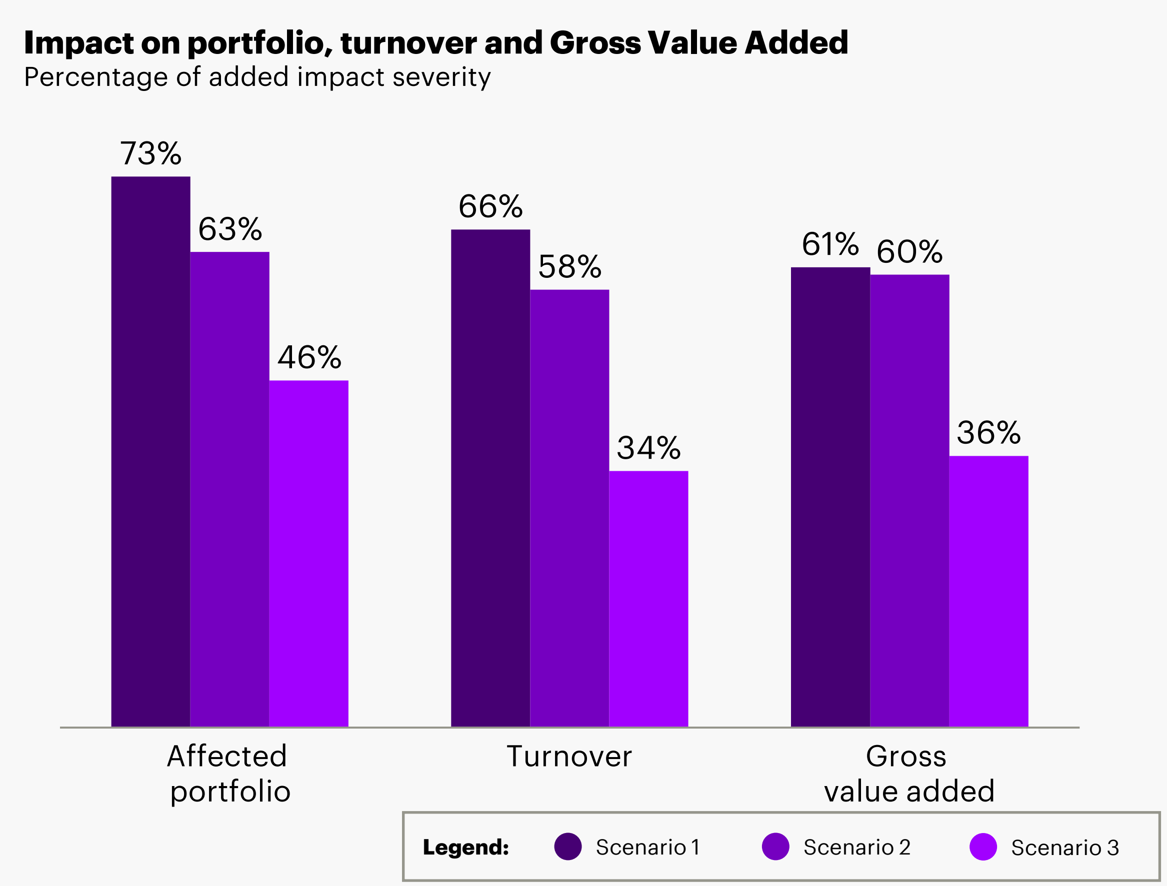
Survey comment by respondent

Restrictions on PFAS would affect the entire value chain of companies, both upstream and downstream

Source: Accenture research, interviews and analysis

PFAS economic impact

Impact on portfolio, turnover and GVA



- **Across all scenarios,** a strong impact would be felt on companies' portfolios, **resulting in a loss of turnover and gross value added**
- **Scenario 1:** It has the **greatest portfolio impact (73%)**, as **absence of suitable alternatives, substantial losses, and elevated costs** place companies at risk of shutdown or relocation
- **Scenario 2:** An extended deadline would only slightly reduce impact severity (63% impact on affected portfolio)
- **Scenario 3:** In the event of a derogation, declines in GVA **(36%)** and turnover **(34%)** are anticipated due **to the increased expenses of PFAS management and monitoring**, but this **impact is milder** than other scenarios

"… Due to the uncertainty and potential impact on our business, some investments have been put on hold until clear guidance on PFAS regulations is provided …"

Survey comment by respondent

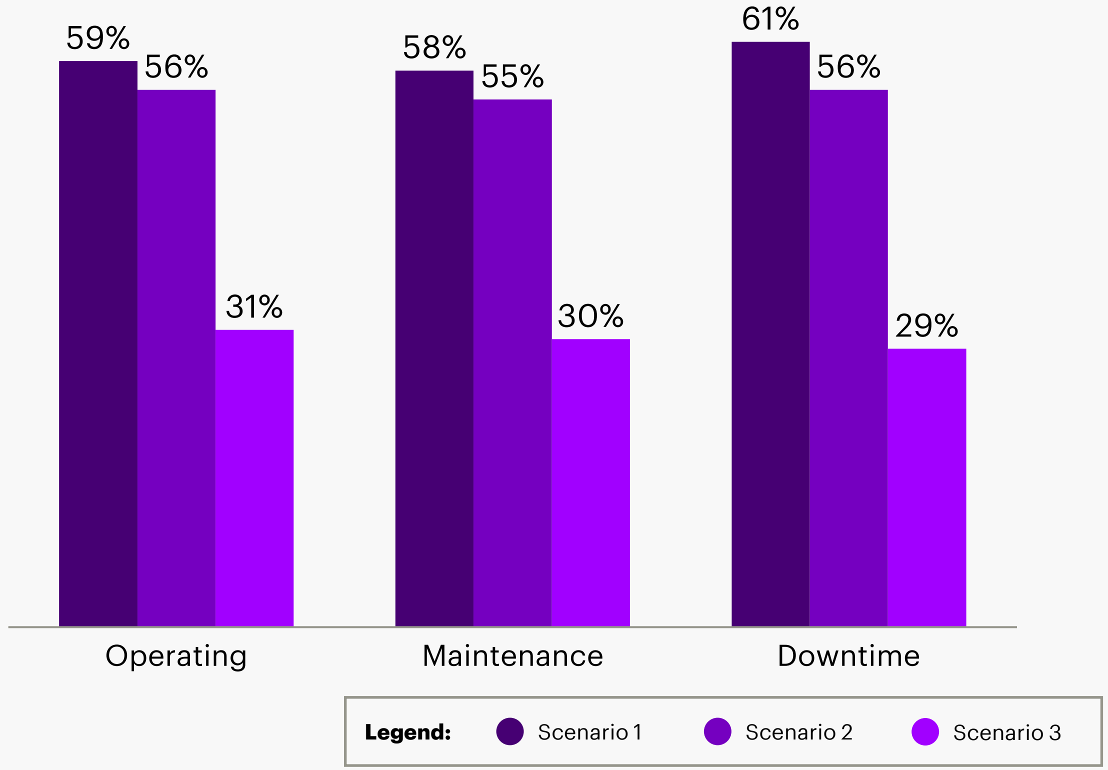
Chemical manufacturing companies could face shutdowns and possible relocations linked to impact on their portfolio

Source: Accenture research, interviews and analysis

PFAS economic impact

OPEX, maintenance & downtime costs impact

OPEX, maintenance and downtime costs impact
Percentage increase from current baseline



- **Across all scenarios**, replacing fluoropolymers in equipment leads to **more frequent maintenance, repairs, and replacements**, as alternatives are **less resilient**, **raising expenses**
- **Scenario 1:** a **high increases in all costs is expected** (e.g., **59% increase in OPEX**). Some companies **anticipate shutdowns or relocations**, as **consequences are difficult to anticipate** due to uncertainty and the lack of alternatives
- **Scenario 2:** Similar outcomes to scenario 1 are expected
- **Scenario 3:** In this scenario a derogation would result in **less severe impacts**, although **an important increase costs related to operations (31%),maintenance (30%), and downtime (29%)** is anticipated

"… For scenario 1 and 2, maintenance costs and frequencies would rise significantly due to the reduced chemical resistance of equipment without PFAS components …"

Survey comment by respondent

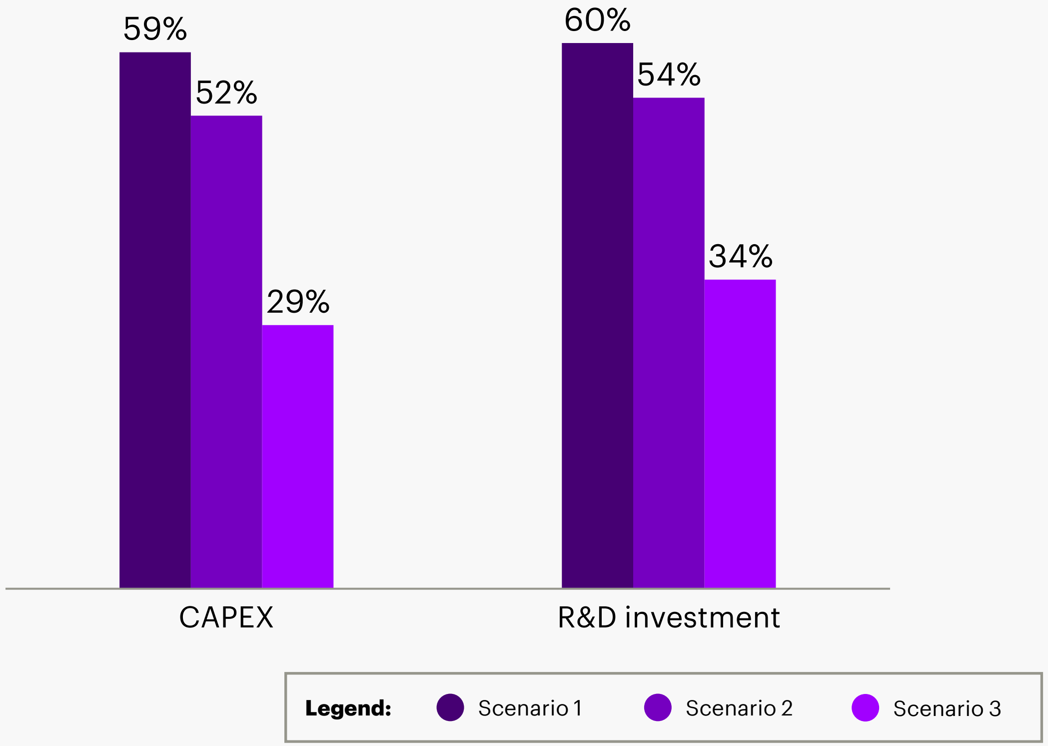
Rising maintenance costs and more frequent shutdowns would increase OPEX, placing companies at a competitive disadvantage

Source: Accenture research, interviews and analysis

PFAS economic impact

CAPEX and R&D costs impact

CAPEX and R&D costs impact
Percentage increase from current baseline



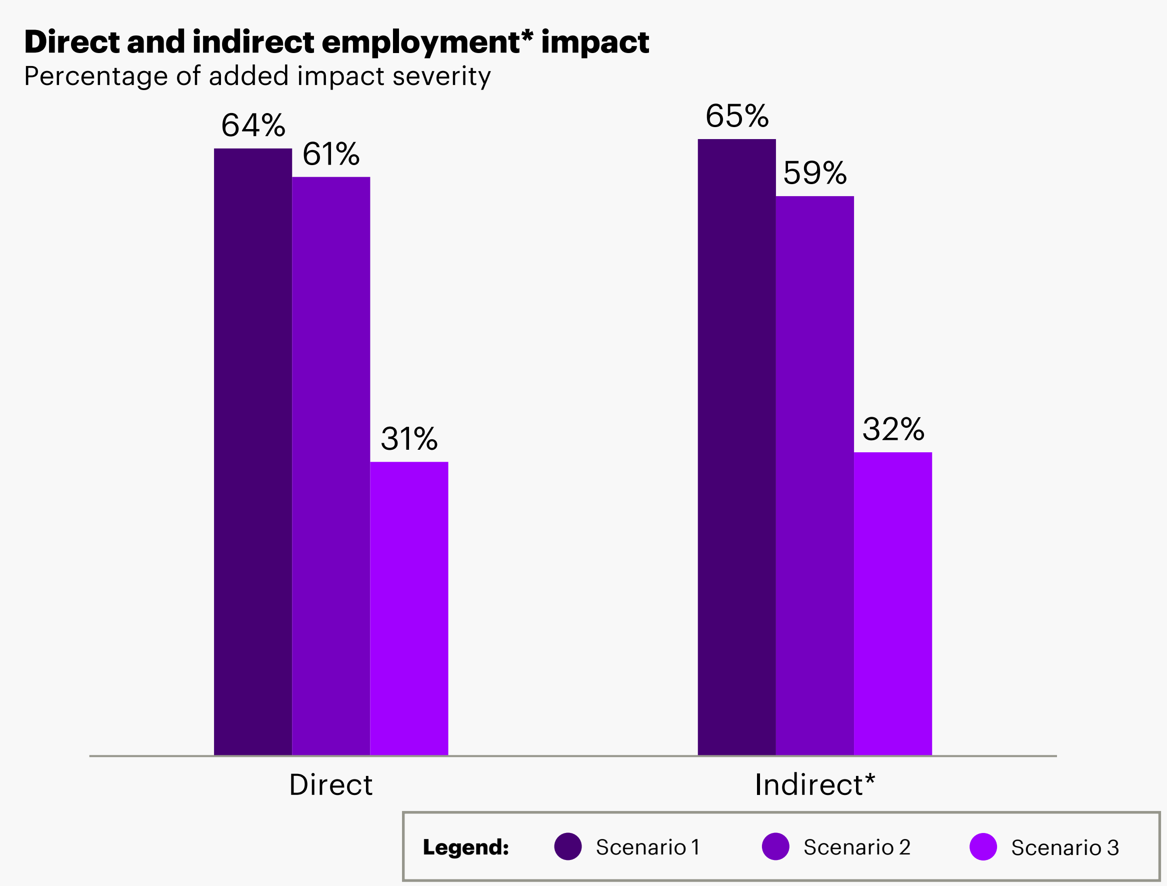
- **Across all scenarios** companies anticipate **rises in CAPEX and R&D** as plants undergo significant transformations and must identify PFAS alternatives
- **Scenario 1:** In the event of a restriction, a significant **increase in CAPEX (59%)** is expected, as some plants must be **overhauled** in a manner comparable to **complete rebuilds**. An important **increase in R&D spending (60%)** is also expected due to sudden and pressing need for PFAS alternatives
- **Scenario 2:** Similar outcomes to scenario 1 are expected, slightly moderated by the extended timeframe
- **Scenario 3:** A derogation sees **an increase in CAPEX (29%)** costs associated with **monitoring and reporting** along with **increase in R&D (34%)** to **search for PFAS alternatives.** These impacts are less severe than in previous scenarios

"… For scenario 1 and 2, increase in CAPEX would be significant due to the need to retrofit our plant …" *Survey comment by respondent*

Implementation of alternatives would lead to rise in CAPEX and R&D spending

PFAS economic impact

Direct and indirect employment* impact



- **Across all scenarios important losses of direct and indirect employment*** are expected, resulting from **lower revenues, plant shutdowns, and relocations** of chemical manufacturing plants. A few companies expect an increase in number of employees due to R&D investments
- **Scenario 1:** Strong impacts are felt across both direct (64%) and indirect (65%) employment
- **Scenario 2:** Relatively similar outcomes to scenario 1 (61% for direct and 59% for indirect)
- **Scenario 3:** A smaller impact **on direct (31%) and indirect (32%) employment** is expected as **increase in employees required for monitoring and reporting** may help offset some of employment loss from reduced productivity

"… Under scenario 1, reduction in employment is expected due to partial shutdown or relocation of the plant […] a knock-on effect could be felt on businesses external to the plant, such as suppliers or contractors …"

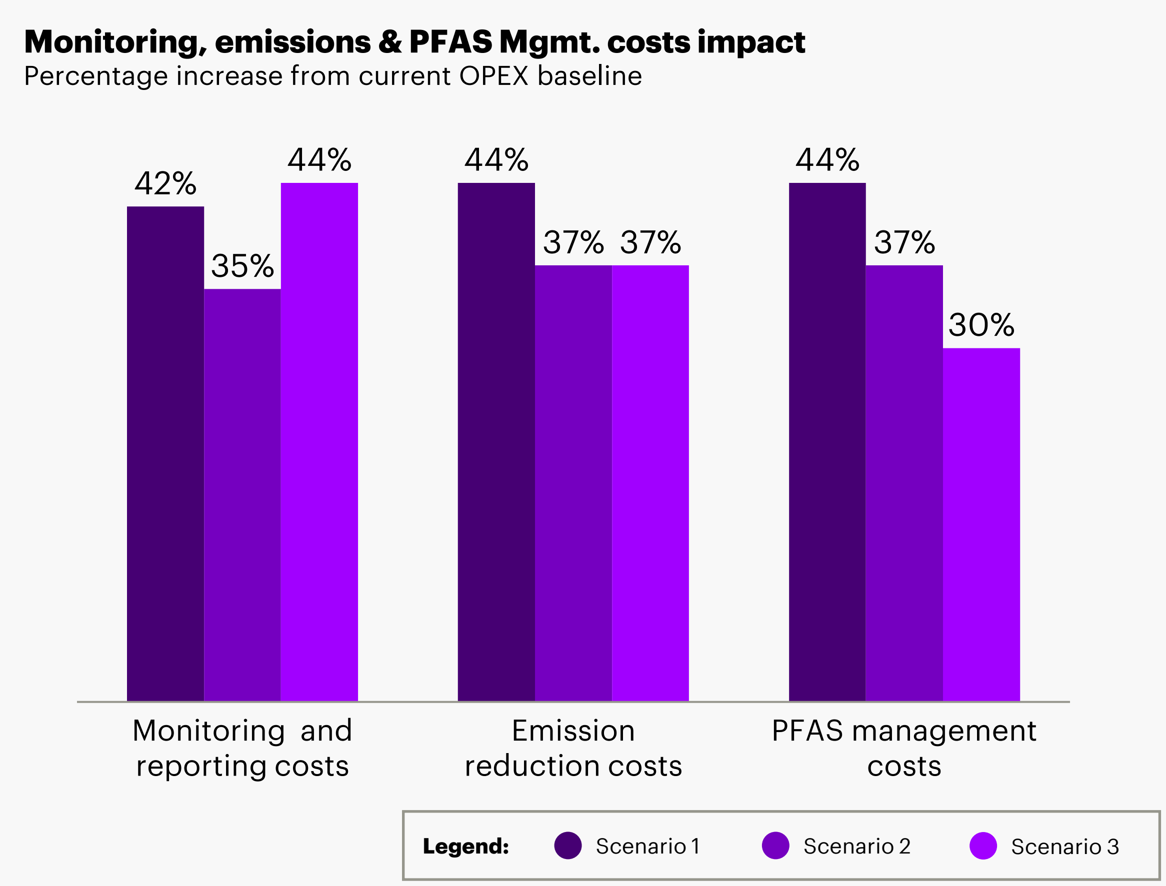
Survey comment by respondent

PFAS restrictions would impact production, thereby affecting direct and indirect employment of chemical manufacturing plants

Note: *Refers to jobs external to the companies, such as subcontractors, suppliers, or local businesses close to the plant
Source: Accenture research, interviews and analysis

PFAS economic impact

Monitoring, emissions & PFAS Mgmt. costs impact



- **Across all scenarios** an **increase in OPEX baseline costs** is anticipated, **due to monitoring and reporting requirements**
- **Scenario 1:** A high increase in **costs related to PFAS managements (44%)** would occur in this scenario. The urgent need for PFAS removals would also lead to **higher emissions reduction costs (44%)** to meet targets
- **Scenario 2:** Similar outcomes to scenario 1 are expected, slightly moderated by the extended timeframe
- **Scenario 3: Monitoring costs would be higher (44%)** than in other scenarios due to the implementation of detailed **substitution and emission reduction plans**

"… Investments would be required to create the necessary infrastructure to manage PFAS and therefore operating costs would rise …"

Survey comment by respondent

Costs due to PFAS management, emissions reductions, and monitoring would impact activity across all scenarios

Source: Accenture research, interviews and analysis

Legend: Scenario 1 Scenario 2 Scenario 3

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Conclusions

- PFAS across equipment are **essential to the operational safety, performance, and competitiveness** of Europe's chemical manufacturing industry and used for longer duration. The **PFAS inventory** across EU chemicals manufacturing equipment is estimated at **23 to 39 kt**, corresponding to an average of **2 to 3 tons per plant**. This inventory is **primarily composed of fluoropolymers**
  - **PTFE is the most used fluoropolymer**, making up, on average, over two-thirds of fluoropolymers by weight in a chemical plant. **Piping (lined and full–fluoropolymer), valves, and gaskets are the main elements containing fluoropolymers**, with piping accounting for 50%, valves 25%, and gaskets 25%. O-rings and expansion joints represent less than 1 % of the share. **F-gases usage remains limited** and specific to equipment related to temperature control
  - Fluoropolymers substitution is complex, **as potential alternatives often fail to meet the set of their unique combination of properties**: temperature resistance, chemical resistance, and mechanical resistance. A **case-by-case assessment** based on specific needs and operating conditions is necessary to identify areas where alternatives could be deployed to replace PFAS
- For these Alternatives, implementation is challenging due to **high operational safety and performance standards**, **expensive refits**, **the length of development cycle** of alternatives and the **scaling of their supply chain**

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Topics

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Fluoropolymers value chain

Materials’ chemical and mechanical properties

Appendix

Abbreviations & Acronyms

AC	Air conditioning	**FEP**	Fluorinated Ethylene Propylene	**KOH**	Potassium hydroxide
AISI 316Ti	Stainless Steel	**FEVE**	Fluoroethylene Vinyl Ether	**LDPE**	Low-Density Polyethylene
CAGR	Compound Annual Growth Rate	**FFKM**	Perfluoroelastomer	**LiBETI**	Lithium bis(pentafluoroethanesulfonyl)imide
CAPEX	Capital expenditure	**FKM**	Fluoroelastomer	**LiBF4**	Lithium tetrafluoroborate
CFC	Chorofluorocarbons	**GHG**	Greenhouse Gas	**LiClO4**	Lithium perchlorate
CMC	Carboxymethyl Cellulose	**GVA**	Gross Value Added	**LiPF6**	Lithium hexafluorophosphate
CMR	Carcinogenic, mutagenic, and toxic to reproduction	**GWP**	Global Warming Potential	**LiTFSI**	Lithium bis(trifluoromethanesulfonyl)imide
CO2	Carbon Dioxide	**HCFC**	Hydrochlorofluorocarbons	**Li-triflate**	Lithium Triflate
CPVC	Chlorinated Polyvinyl Chloride	**HDPE**	High-Density Polyethylene	**LPG**	Liquefied Petroleum Gas
DN	Diameter Nominal	**HFC**	Hydrofluorocarbons	**MFA**	Methyl Fluoroacetate
ECTFE	Etylene Chlorotrifluorethylene	**HFO**	Hydrofluorolefins	**MoS2**	Molybdenum disulfide
EPDM	Ethylene Propylene Diene Monomer	**HSE**	Health, Safety and Environment	**NBR**	Nitrile Butadiene Rubber
ETFE	Ethylene Tetrafluoroethylene	**INCONEL 718**	Nickel-chromium alloy	**OEM**	Original Equipment Manufacturer

Appendix

Abbreviations & Acronyms

OPEX	Operating Expenditure	**PU**	Polyurethane	**R-1270**	Propylene
PCTFE	Polychlorotrifluoroethylene	**PVC**	Polyvinyl Chloride	**R-1336mzz-Z**	(2Z)-1,1,1,4,4,4-hexafluorobut-2-ene
PEEK	Polyether Ether Ketone	**PVDF**	Polyvinylidene Fluoride	**R-134a**	1-Chloro-3,3,3-trifluoropropene
PES	Polyethersulfone	**PVDFF**	Perfluorinated Vinylidene Fluoride	**R-143a**	1,1,1-Trifluoroethane
PET	Polyethylene Terephthalate	**R&D**	Research and development	**R-152**	1,1-Difluoroethane
PFA	Perfluoroalkyl	**R&I**	Research and innovation	**R-170**	Ethane
PFAS	Per and polyfluoroakyl substances	**R-123**	2,2-Dichloro-1,1,1-trifluoroethane	**R-22**	Chlorodifluoromethane
PFPE	Perfluoropolyether	**R-1233zd**	Trans-1-chloro-3,3,3-trifluoropropene	**R-290**	Propane
PP	Polypropylene	**R1233zd(E)**	1,1,1-Trifluoro-3,3,3-trifluoropropene	**R-32**	Difluoromethane
PPE	Personal Protective Equipment	**R-1234yf**	2,3,3,3-Tetrafluoropropene	**R-365mfc**	1,1,1,3,3-Pentafluorobutane
PPV	Poly(p-phenylene vinylene)	**R-1234ze**	Trans-1,3,3,3-Tetrafluoroprop-1-ene	**R-401A**	Blend of R-22, R-152a, and R-124
PS	Polystyrene	**R-124**	2-Chloro-1,1,1,2-tetrafluoroethane	**R-404A**	Blend of R-125, R-143a, and R-134a
PTFE	Polytetrafluoroethylene	**R-125**	Pentafluoroethane (1,1,1,2,2-pentafluoroethane)	**R-407c**	Blend of R-32, R-125, and R-134a

Appendix

Abbreviations & Acronyms

R-410A	Blend of R-32, and R-125	**SBR**	Styrene Butadiene Rubber		
R-417A	Blend of R-125, R-134a, and R-600a	**SF6**	Sulfur hexafluoride		
R-422D	Blend of R-134a, R-22, and R-125	**TFE/P**	Tetrafluoroethylene/Perfluoropropylene		
R-449A	Blend of R-1235yf, R-134a, and R-125	**UV**	UltraViolet		
R-450A	Blend of R-134a and R-1234ze	**XLPE**	Cross Linked Polyethylene		
R-452A	Blend of R-32 and R-1234yf				
R-507	Blend of R-125 and R-143a				
R-507A	Blend of R-125 and R-143a				
R-513A	Blend of R-134a and R-1234yf				
R-600a	Isobutane				
R-717	Ammonia				
R-744	Carbon dioxide				
ROCE	Return on Capital employed				

Appendix

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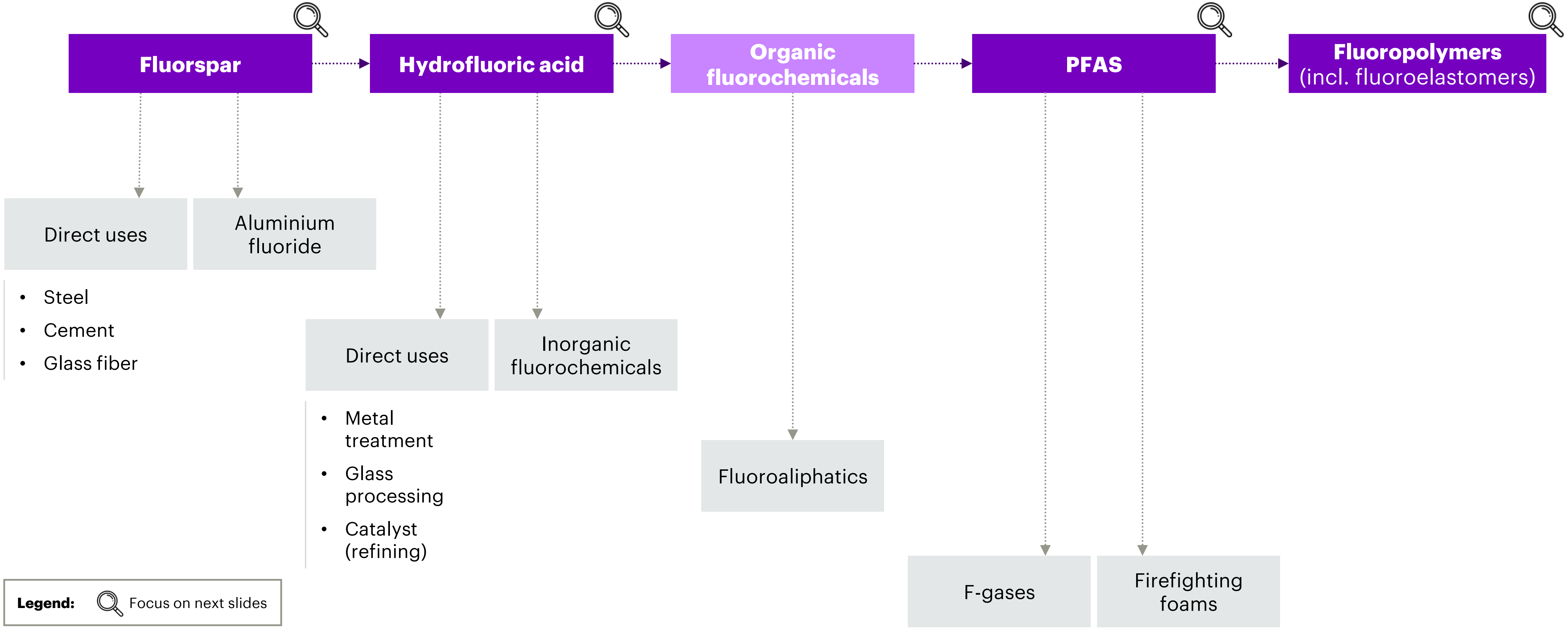
Appendix

Fluoropolymers value chain

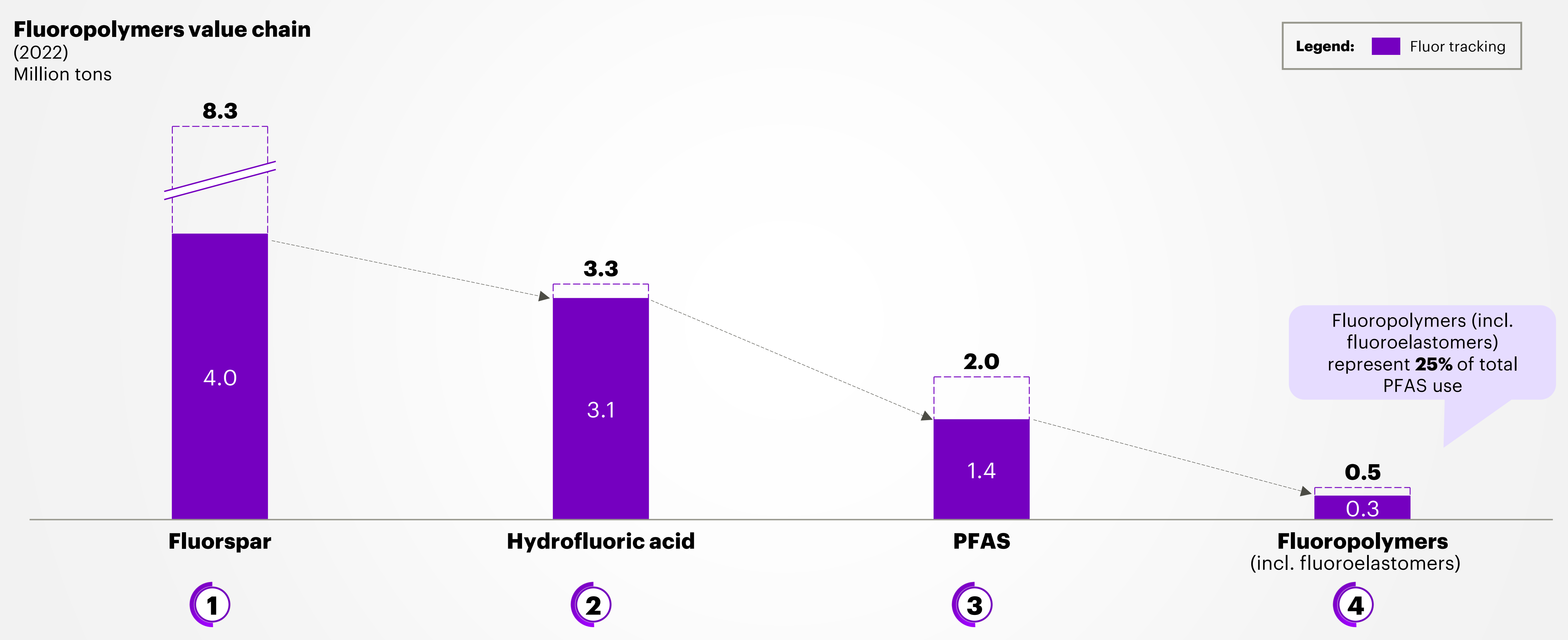
Fluoropolymers value chain



Source: Accenture research, interviews and analysis

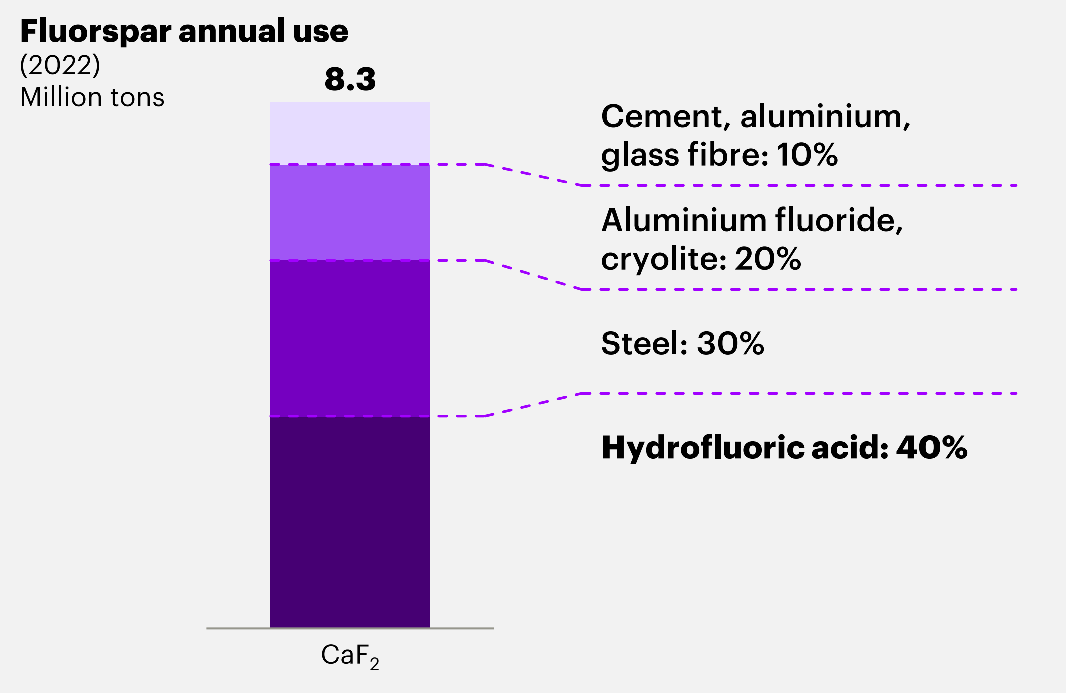
Appendix

Fluoropolymers value chain



Appendix

Fluoropolymers value chain - Fluorspar



- Fluorspar is the primary raw material for the production of **hydrofluoric acid**, which serves as a precursor to most fluorine-based chemicals
- In **steel manufacturing**, fluorspar is essential to act as flux agent to remove impurities
- Fluorspar is used to produce **aluminium fluoride**, which plays a crucial role as additive in the aluminium production process
- In high-temperature industrial processes including **cement, aluminium and glass**, fluorspar is a key raw material to improve efficiency, quality and performance

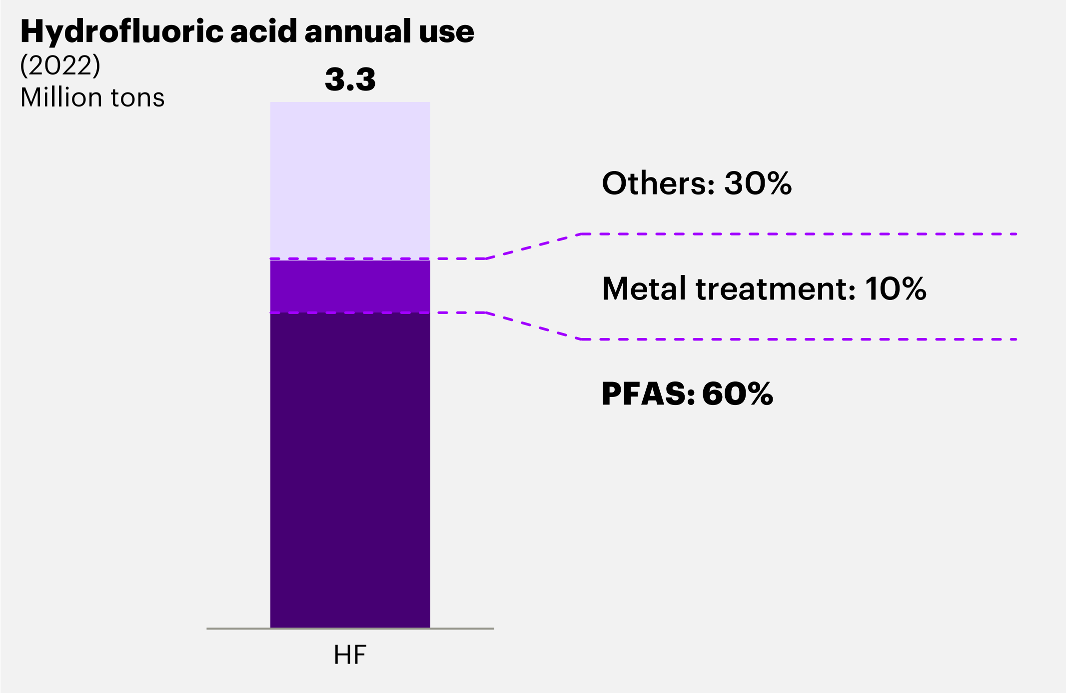
Fluor tracking

In 2022, based on molecular weight, the total quantity of **Fluor** in the world's Fluorspar (CaF_2) production was estimated at **4 million tons***

Note: *m(F) = m(CaF_2) x 2M(F) / M (CaF_2) where m= 8.3Mt, M(F) = 19g/mol and M(CaF_2)= 78g/mol
Source: AMSEC, Accenture research and analysis

Appendix

Fluoropolymers value chain – Hydrofluoric acid



- **PFAS**, the largest hydrofluoric acid derivatives, are essential as refrigerants and polymer precursors, used in various industrial applications
- **Metal treatment and glass processing** (Others) represent the main direct uses
- **Other uses** include uranium fuel production, uranium hexafluoride, petroleum alkylation catalyst, inorganic and other aliphatic fluorochemicals

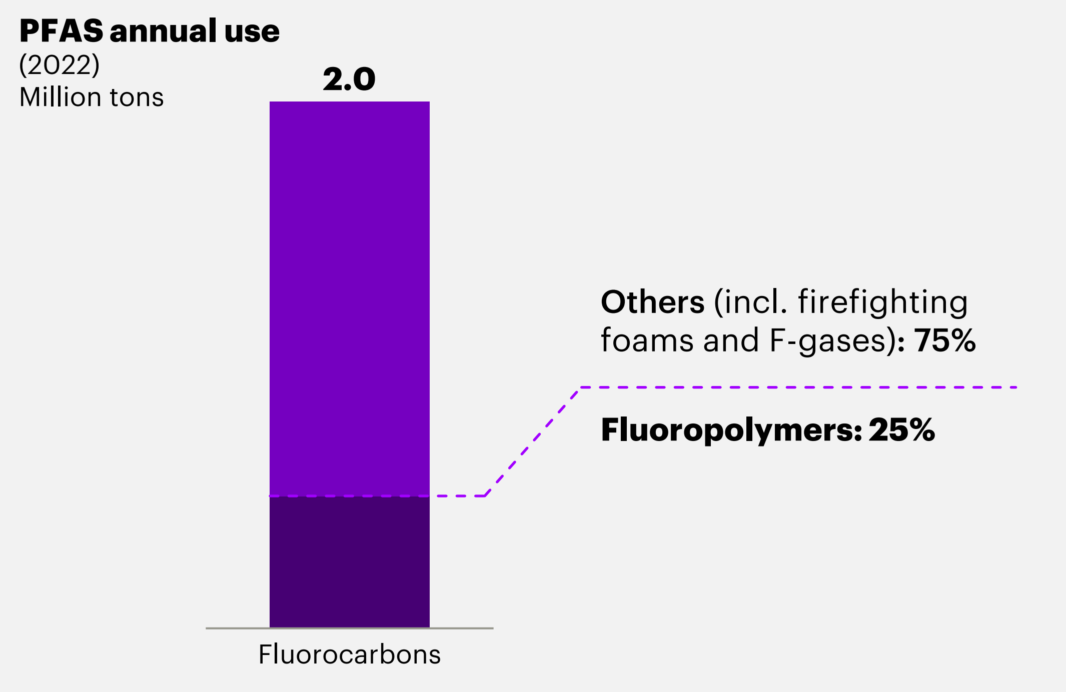
Fluor tracking

In 2022, the total quantity of **Fluor** in the world's hydrofluoric acid (HF) production was estimated at **3.1 million tons***

Note: *m(F) = m(HF) x M(F) / M (HF) where m(HF) = 3.3Mt, M(F) = 19g/mol and M(HF)= 20g/mol
Source: Market, AMSEC, Market Research Future, Accenture research and analysis

Appendix

Fluoropolymers value chain - PFAS



- PFAS use is largely driven by their role as polymer precursor in production of **fluoropolymers** for its unique properties (e.g., chemical inertness, heat insulation)
- **F-gases** are essential to refrigeration and air conditioning for efficient cooling, but regulatory shifts is driving innovation in low-global-warming alternatives*
- **Firefighting foams** using PFAS are key to control flammable liquid fires, especially for industrial fire protection systems, airports, and fuel storage facilities
- **Other uses** include aerosol propellants and solvent cleaning

Fluor tracking

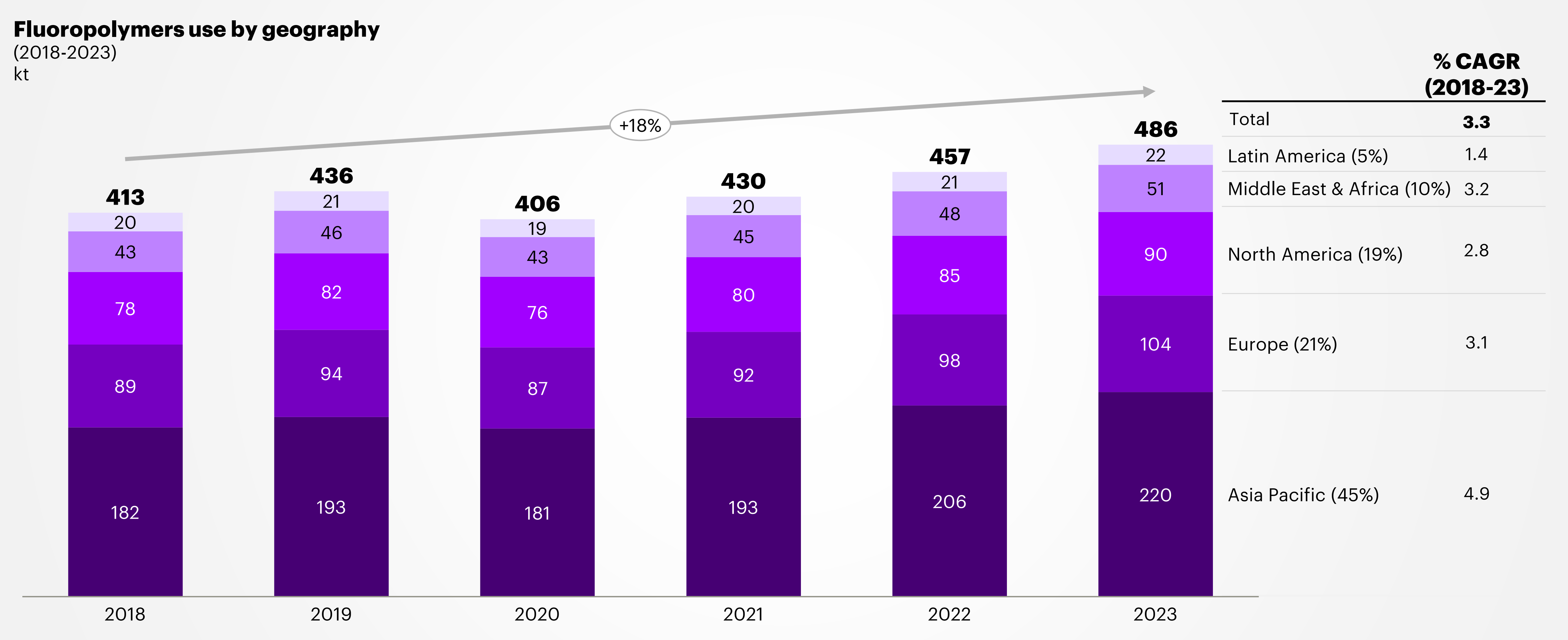
In 2022, the total quantity of **Fluor** in the world's PFAS production is estimated at **1.4 million tons****

Note: *(EU) 2024/513 implements decreasing quotas on f-gases in the European Union based on their global warming potential; **m(F) = 0.7 x m(PFAS) based on the average ratio of fluor content by PFAS molecule

Source: Grand View Research, IHS Market, AMSEC, Accenture research and analysis

Appendix

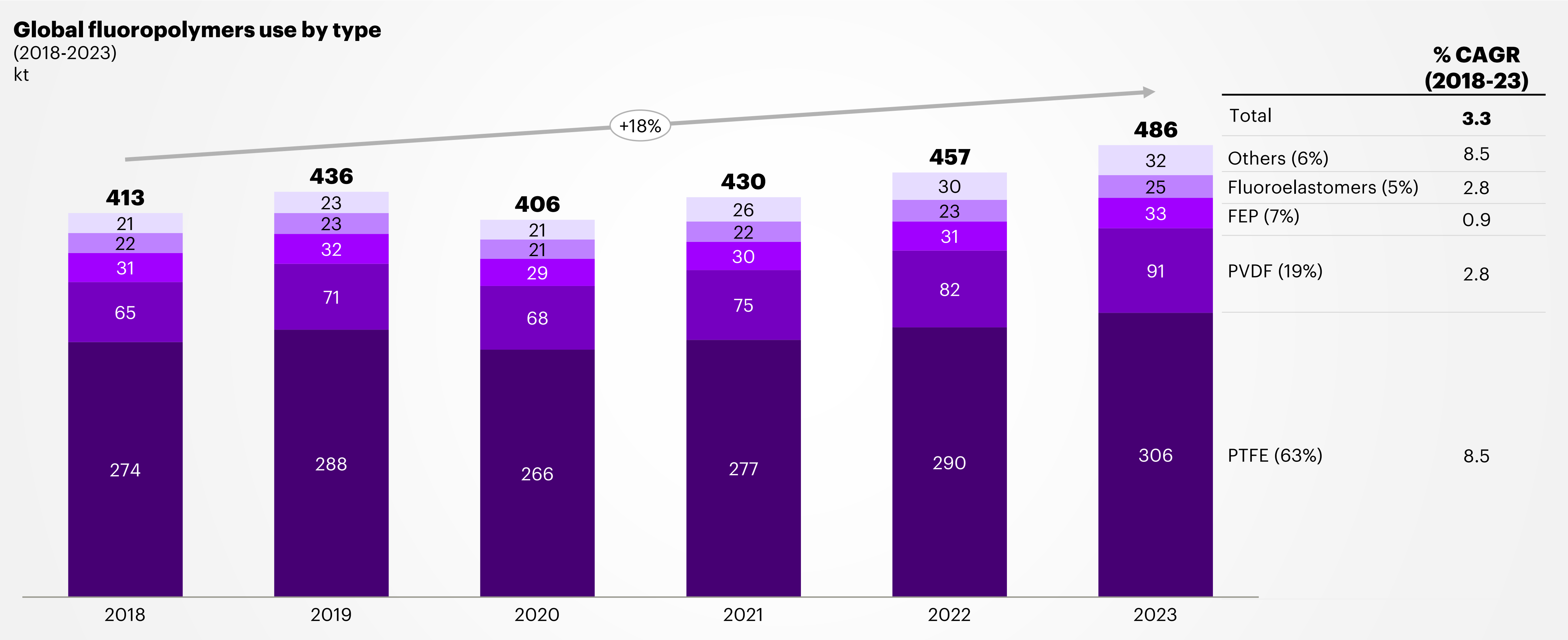
Fluoropolymers value chain - Fluoropolymers



Source: Grand View Research, Accenture research and analysis

Appendix

Fluoropolymers value chain - Fluoropolymers



Source: Grand View Research, Accenture research and analysis

Appendix

Chemical property for fluoropolymers

Category	Chemical substance	PTFE	PVDF	ETFE	PFA	FEP	FKM	FFKM	PCTFE	ECTFE
Acids (strong & weak)	Sulfuric acid (H_2SO_4)	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Hydrochloric acid (HCl)	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Nitric acid (HNO_3)	Compatible	Compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Compatible	Compatible
	Acetic acid	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Compatible	Compatible	Compatible
Bases (strong & weak)	Sodium hydroxide (NaOH)	Compatible	Low compatibility	Compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Compatible
	Potassium hydroxide (KOH)	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Compatible	Compatible	Compatible
Oxidizers & reactive chemicals	Hydrogen peroxide (H_2O_2)	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Potassium permanganate ($KMnO_4$)	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Bromine (Br_2)	Compatible	Compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Compatible	Compatible
	Sodium chlorite ($NaClO_2$)	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Formaldehyde (CH_2O)	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Acetaldehyde (C_2H_4O)	Compatible	Compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Compatible	Compatible
Solvents (polar & non-polar)	Methanol	Compatible	Not compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Compatible	Compatible
	Ethanol	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Benzene	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Toluene	Compatible	Compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Compatible	Compatible
	Acetone	Compatible	Low compatibility	Compatible	Compatible	Compatible	Not compatible	Compatible	Compatible	Compatible
	Methyl acetate	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Compatible	Compatible	Compatible

Source: Accenture research, interviews and analysis

Legend: Compatible · Low compatibility · Not compatible

Appendix

Chemical property for plastics

Category	Chemical substance	HDPE	LDPE	PP	PVC	PET	PU	PS	Epoxy	Polyimide	PEEK
Acids (strong & weak)	Sulfuric acid (H_2SO_4)	Low compatibility	Compatible	Low compatibility	Compatible	Compatible	Low compatibility	Not compatible	Not compatible	Compatible	Not compatible
	Hydrochloric acid (HCl)	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Not compatible	Not compatible	Compatible	Not compatible
	Nitric acid (HNO_3)	Low compatibility	Low compatibility	Not compatible	Low compatibility	Low compatibility	Not compatible	Low compatibility	Not compatible	Compatible	Not compatible
	Acetic acid	Compatible	Compatible	Low compatibility	Not compatible	Compatible	Not compatible	Low compatibility	Not compatible	Compatible	Low compatibility
Bases (strong & weak)	Sodium hydroxide (NaOH)	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Potassium hydroxide (KOH)	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Low compatibility	Compatible	Not compatible	Compatible
Oxidizers & reactive chemicals	Hydrogen peroxide (H_2O_2)	Compatible	Compatible	Not compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Compatible	Compatible
	Potassium permanganate ($KMnO_4$)	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Compatible	Low compatibility	Compatible	Compatible
	Bromine (Br_2)	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Compatible	Not compatible
	Sodium chlorite ($NaClO_2$)	Low compatibility	Low compatibility	Compatible	Not compatible	Low compatibility	Not compatible	Not compatible	Compatible	Compatible	Compatible
	Formaldehyde (CH_2O)	Compatible	Compatible	Compatible	Not compatible	Compatible	Not compatible	Not compatible	Compatible	Compatible	Compatible
	Acetaldehyde (C_2H_4O)	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible
Solvents (polar & non-polar)	Methanol	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Low compatibility	Not compatible	Compatible	Compatible
	Ethanol	Compatible	Compatible	Compatible	Compatible	Compatible	Not compatible	Compatible	Compatible	Compatible	Compatible
	Benzene	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible
	Toluene	Not compatible	Low compatibility	Low compatibility	Not compatible	Low compatibility	Not compatible	Not compatible	Not compatible	Compatible	Compatible
	Acetone	Not compatible	Compatible	Compatible	Not compatible	Compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible
	Methyl acetate	Low compatibility	Low compatibility	Compatible	Not compatible	Compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible

Source: Accenture research, interviews and analysis

Legend: Compatible / Low compatibility / Not compatible

Appendix

Chemical property for elastomers and other materials

Category	Chemical substance	SBR	NBR	EPDM	Silicone	Ceramic	Glass	Graphite
Acids (strong & weak)	Sulfuric acid (H_2SO_4)	Not compatible	Not compatible	Compatible	Not compatible	Compatible	Compatible	Compatible
	Hydrochloric acid (HCl)	Not compatible	Not compatible	Compatible	Not compatible	Not compatible	Compatible	Not compatible
	Nitric acid (HNO_3)	Not compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible	Not compatible
	Acetic acid	Compatible	Not compatible	Low compatibility	Compatible	Compatible	Compatible	Compatible
Bases (strong & weak)	Sodium hydroxide (NaOH)	Compatible	Low compatibility	Compatible	Compatible	Compatible	Low compatibility	Compatible
	Potassium hydroxide (KOH)	Compatible	Not compatible	Compatible	Low compatibility	Compatible	Compatible	Compatible
Oxidizers & reactive chemicals	Hydrogen peroxide (H_2O_2)	Not compatible	Not compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Potassium permanganate ($KMnO_4$)	Compatible	Low compatibility	Compatible	Compatible	Compatible	Low compatibility	Compatible
	Bromine (Br_2)	Not compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible	Not compatible
	Sodium chlorite ($NaClO_2$)	Compatible	Compatible	Compatible	Compatible	Low compatibility	Compatible	Not compatible
	Formaldehyde (CH_2O)	Low compatibility	Low compatibility	Compatible	Compatible	Compatible	Compatible	Compatible
	Acetaldehyde (C_2H_4O)	Low compatibility	Not compatible	Not compatible	Compatible	Compatible	Compatible	Compatible
Solvents (polar & non-polar)	Methanol	Compatible	Low compatibility	Compatible	Compatible	Compatible	Compatible	Compatible
	Ethanol	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
	Benzene	Not compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible	Compatible
	Toluene	Not compatible	Not compatible	Low compatibility	Not compatible	Compatible	Compatible	Compatible
	Acetone	Not compatible	Not compatible	Compatible	Not compatible	Compatible	Compatible	Compatible
	Methyl acetate	Not compatible	Not compatible	Not compatible	Not compatible	Compatible	Compatible	Compatible

Source: Accenture research, interviews and analysis

Legend: Compatible · Low compatibility · Not compatible

Appendix

Chemical property for metals and alloys

Category	Chemical substance	Stainless steel	Nickel alloy*	Copper	Titanium	Hastelloy
Acids (strong & weak)	Sulfuric acid (H_2SO_4)	Compatible	Compatible	Not compatible	Not compatible	Compatible
	Hydrochloric acid (HCl)	Not compatible	Low compatibility	Not compatible	Not compatible	Compatible
	Nitric acid (HNO_3)	Compatible	Low compatibility	Not compatible	Compatible	Compatible
	Acetic acid	Compatible	Compatible	Compatible	Compatible	Compatible
Bases (strong & weak)	Sodium hydroxide (NaOH)	Compatible	Compatible	Not compatible	Not compatible	Compatible
	Potassium hydroxide (KOH)	Compatible	Compatible	Compatible	Not compatible	Compatible
Oxidizers & reactive chemicals	Hydrogen peroxide (H_2O_2)	Compatible	Compatible	Not compatible	Compatible	Compatible
	Potassium permanganate ($KMnO_4$)	Compatible	Compatible	Compatible	Compatible	Compatible
	Bromine (Br_2)	Not compatible	Compatible	Not compatible	Not compatible	Compatible
	Sodium chlorite ($NaClO_2$)	Low compatibility	Compatible	Compatible	Compatible	Compatible
	Formaldehyde (CH_2O)	Compatible	Compatible	Compatible	Compatible	Compatible
	Acetaldehyde (C_2H_4O)	Compatible	Compatible	Compatible	Compatible	Compatible
Solvents (polar & non-polar)	Methanol	Compatible	Compatible	Compatible	Compatible	Compatible
	Ethanol	Compatible	Compatible	Compatible	Compatible	Compatible
	Benzene	Compatible	Compatible	Compatible	Compatible	Compatible
	Toluene	Compatible	Compatible	Compatible	Compatible	Compatible
	Acetone	Compatible	Compatible	Compatible	Compatible	Compatible
	Methyl acetate	Compatible	Compatible	Compatible	Compatible	Compatible

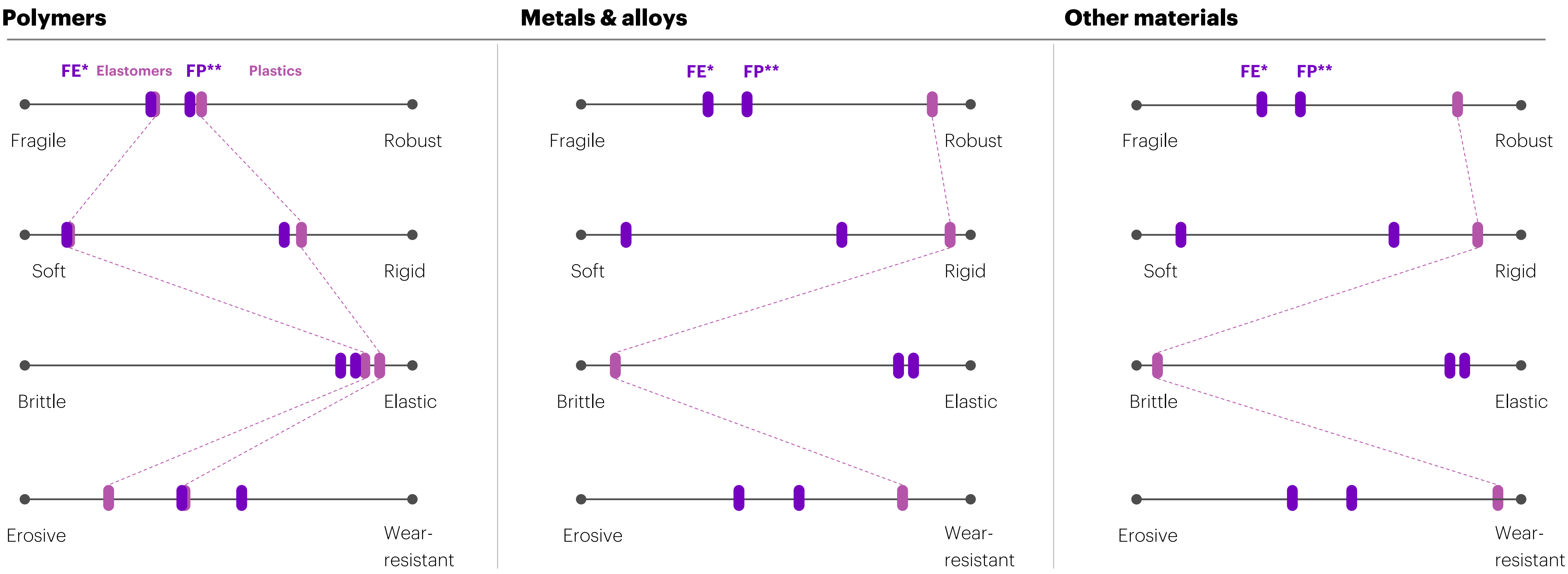
Note: *INCONEL 718
Source: Accenture research, interviews and analysis

Legend: Compatible · Low compatibility · Not compatible

Appendix

Mechanical properties

Polymers offer **flexible and durable mechanical profile**, close to fluoropolymers properties

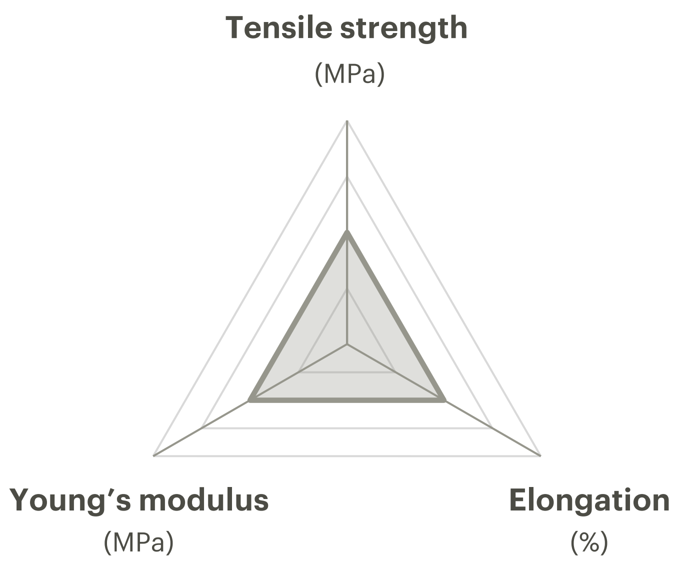


Note: *Fluoroelastomers; **Fluoropolymers
Source: Accenture research, interviews and analysis

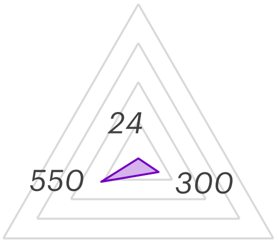
Legend: Fluoropolymers Alternatives

Appendix

Fluoropolymers mechanical resistance



- **Tensile strength:** maximum stress before breaking. Higher value means greater strength and resistance
- **Young's modulus:** resistance to elastic deformation. Higher values means greater rigidity, lower values indicates flexibility
- **Elongation**: maximum elasticity before breaking. Higher value means greater flexibility, lower values indicates brittleness



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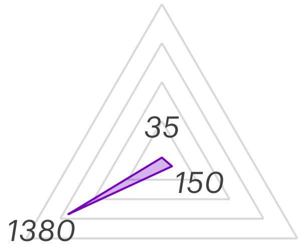

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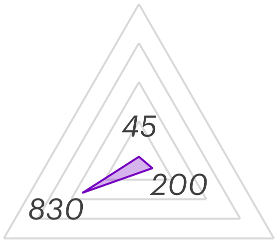

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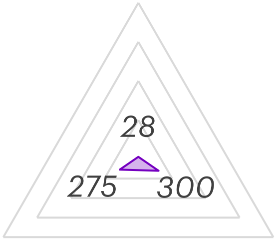

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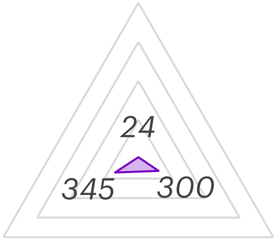

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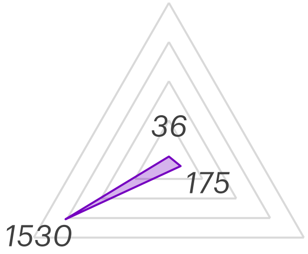

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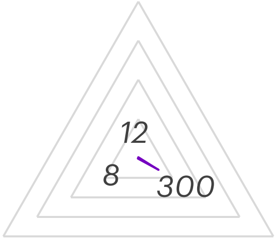

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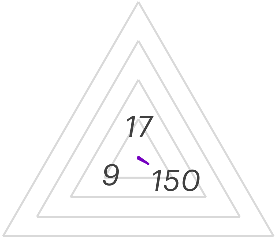

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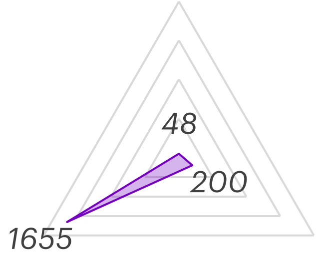
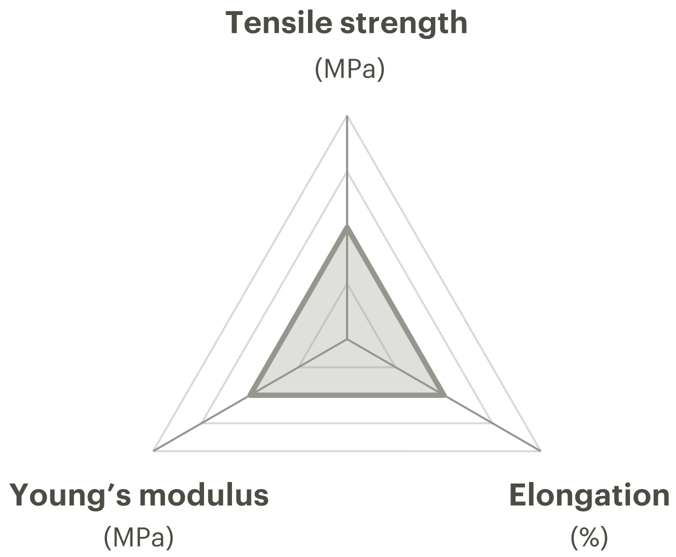


ECTFE

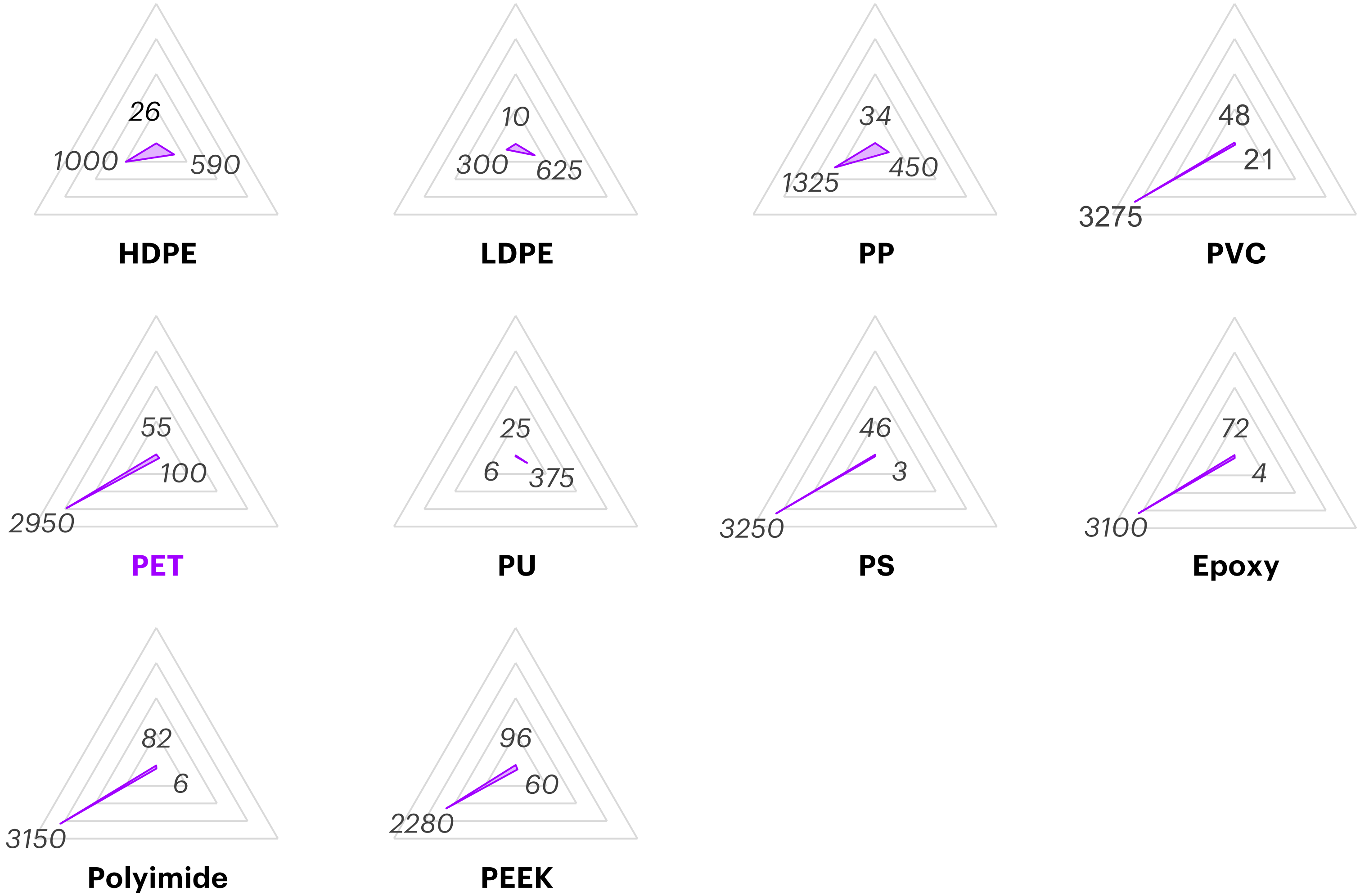
Source: Accenture research, interviews and analysis

Appendix

Plastics mechanical resistance



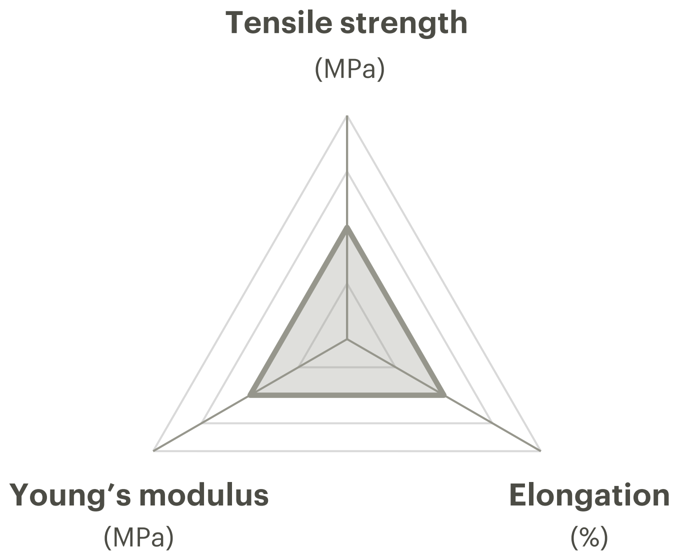
- **Tensile strength:** maximum stress before breaking. Higher value means greater strength and resistance
- **Young's modulus:** resistance to elastic deformation. Higher values means greater rigidity, lower values indicates flexibility
- **Elongation**: maximum elasticity before breaking. Higher value means greater flexibility, lower values indicates brittleness



Source: Accenture research, interviews and analysis

Appendix

Elastomers and other materials mechanical resistance



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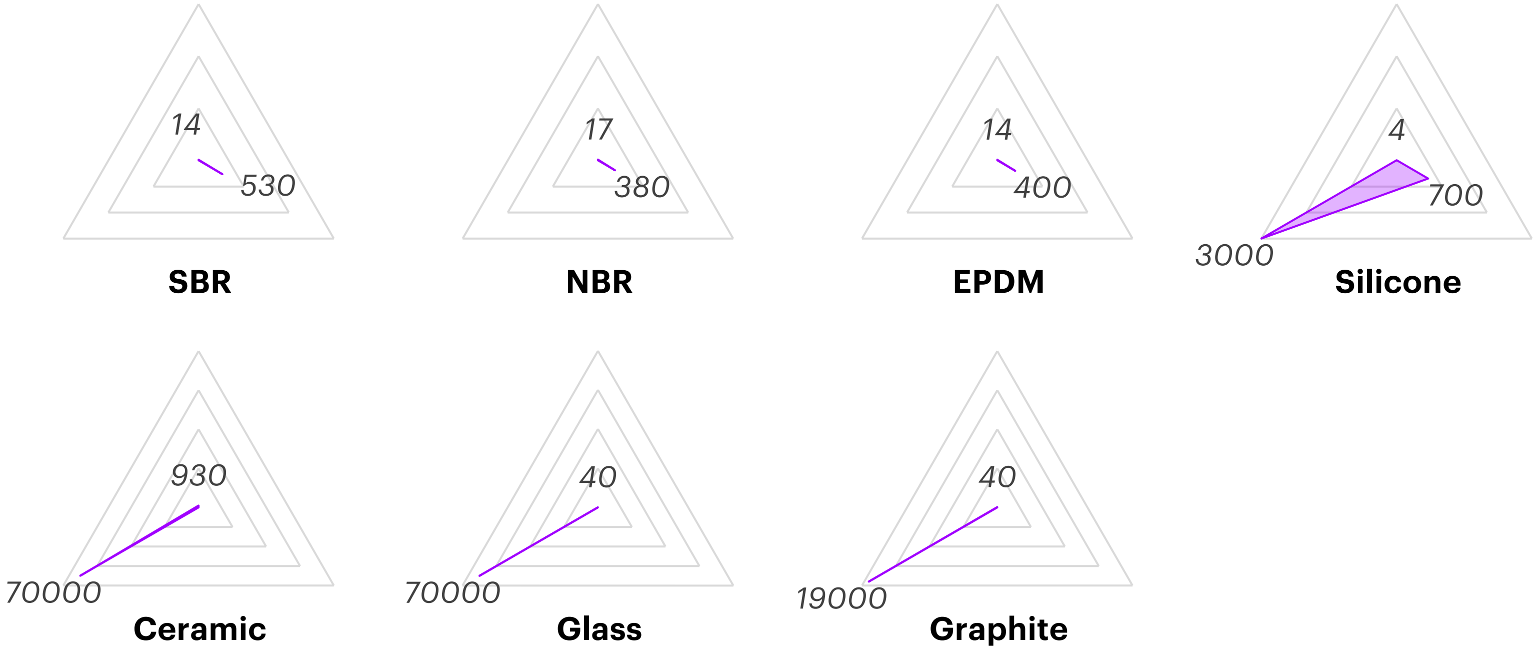
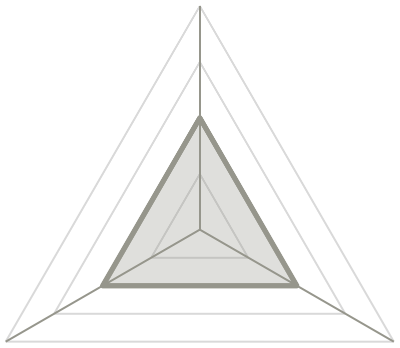


Source: Accenture research, interviews and analysis

Appendix

Metals and alloys mechanical resistance

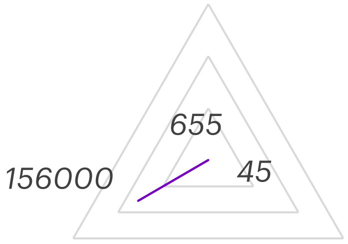
Tensile strength
(MPa)



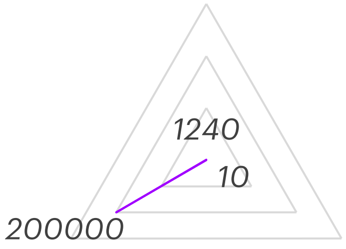
Young's modulus
(MPa)

Elongation
(%)

- **Tensile strength:** maximum stress before breaking. Higher value means greater strength and resistance
- **Young's modulus:** resistance to elastic deformation. Higher values means greater rigidity, lower values indicates flexibility
- **Elongation**: maximum elasticity before breaking. Higher value means greater flexibility, lower values indicates brittleness

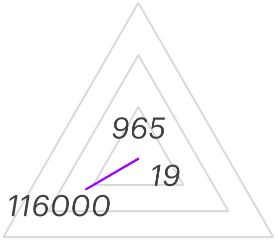


Stainless steel

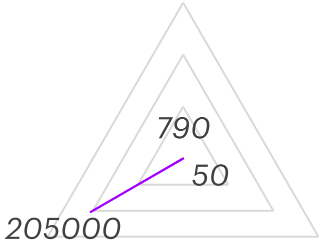


Nickel alloy

Copper



Titanium



Hastelloy

Source: Accenture research, interviews and analysis