CONVERSIO
Market & Strategy

Final Report

Fluoropolymer waste in Europe 2020

– End-of-life (EOL) analysis of fluoropolymer applications, products and associated waste streams

Elaborated for pro-K

July 2022

Main objective and conclusion

Main objective

The report ‘Fluoropolymer waste in Europe 2020‘ was initiated to provide detailed information about the end-of-life fate of fluoropolymer applications, products and associated waste streams. The report has qualitative and quantitative character.

This report delivers an in-depth description on how and where fluoropolymer containing products and corresponding wastes are generated and what happens to the collected fractions at the end of their life. Quantities of fluoropolymer waste are included as far as possible based on an end-of-life fluoropolymer (and relevant fluoropolymer containing products) lifetime assessment model.

A correlation matrix between fluoropolymer applications and the penetration of relevant waste streams (by mass in kt and %) was developed and the waste treatment route (recycling, energy recovery and landfill) is shown.

- Identification where fluoropolymer applications and products end up at the end of their life including re-use of processing scrap and recycling of either pre- or post-consumer fluoropolymer waste (either mechanical, e.g., conversion into PTFE micro powders or chemical) in the EU.
- Identification of major waste streams in which the fluoropolymer applications and products end up incl. total volumes in kt as well as the penetration of fluoropolymers (in kt and %) in the EU.

Conclusion

- In 2020, around 40 kt of fluoropolymer materials were sold to EU fluoropolymer product manufacturers. 23.5 kt of fluoropolymer waste were collected, either in commingled waste streams or partly in source separated waste fractions.
- Almost 84% of all fluoropolymer applications were incinerated at the end of their life in energy recovery (MSWI ~72%) or thermal destruction (metal recycling ~12%) processes. 13% of the collected fluoropolymer waste was landfilled and around 3% was recycled.
- End-of-life fluoropolymer production and processing equipment used for different industrial segments, such as Chemical, Energy, Food & beverage, Pharma and Semiconductor accounted for the major share of the total fluoropolymer waste quantity collected (~13 kt).
- The overall fluoropolymer penetration in all waste streams was less than 0.01% by weight. In comparison, plastics in total accounted for about 4.8% of the total waste collection volume (excl. mineral fractions).
- Chemical recycling of fluoropolymer waste offers the opportunity to produce virgin-like fluoropolymer raw materials for the production of goods and products without quality limitations. However, building robust supply chains for large-scale and economical feasible recycling processes is one of the most important issues to be addressed in the coming years.

Conversio Market & Strategy GmbH

About Conversio

Conversio employees specialize in b2b research and consultancy and work in the field of plastics production, processing and waste management more than 25 years. In 2018 Conversio conducted a fluoropolymer analysis focusing on potential recycling opportunities on behalf of the PlasticsEurope Fluoropolymer project group.

In March 2022, Conversio was commissioned to conduct a new report with focus on the end-of-life scenario of fluoropolymer products and applications by the industry association Pro-K.

Christoph Lindner
+49 (0) 6021 / 9219991
c.lindner@conversio-gmbh.com

Hendrik Beylage
+49 (0) 6021 / 9219996
h.beylage@conversio-gmbh.com

Julia Hein
+49 (0) 6021 / 9219997
j.hein@conversio-gmbh.com

Conversio Market & Strategy GmbH
Am Glockenturm 6
63814 Mainaschaff
Germany

+49 (0) 6021 1506 700
info@conversio-gmbh.com
www.conversio-gmbh.com

Agenda

List of abbreviations

ABS	Acrylonitrile butadiene-styrene copolymer
AFRA	Aircraft fleet recycling association
ASR	Auto shredder residue
B&C	Building & construction
C&I	Commercial & industrial
CAPA	Centre for aviation
CCL	Copper cladded laminates
CPI	Chemical, process & industrial
ELV	End-of-life vehicle
EOL	End-of-life
ETFE	Ethylene tetrafluoroethylene
EU	abbreviated for EU27 + Norway, Switzerland, UK
EV	Electric vehicle
FEP	Fluorinated ethylene propylene
FKM	Fluor-rubber/caoutchouc
FP	Fluoropolymers
HVACR	Heating, ventilation, air conditioning, refrigeration
kt	kilo tonnes
LCA	Life cycle analysis

LCV	Light commercial vehicle
MSW	Municipal solid waste
MSWI	Municipal solid waste incineration
PCB	Printed circuit boards
PCTFE	Polychlorotrifluoro ethylene
PE-HD	High-density polyethylene
PFA	Perfluoroalkoxy
PP	Polypropylene
PS	Polystyrene
PTFE	Polytetrafluorethylene
PV	Photovoltaic
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
PVF	Polyvinyl fluoride
RDF	Refuse derived fuel
SLF	Shredder-light fraction
SRF	Solid recovered fuel
t	tonnes (metric)
WEEE	Waste from electrical and electronic equipment

Initial situation, frame and target

Fluoropolymers are high-tech polymers with fluorine atoms directly attached to their carbon backbone. They are plastics which are virtually chemically inert, non-wetting, non-stick, and highly resistant to temperature, fire and weather. These polymers are used various applications and different industries, e.g., transportation, chemical process industry, (consumer-)electronics, pharmaceutical industry.

Since the discovery of PTFE in 1938, fluoropolymers have become critical components in numerous technologies, industrial processes and everyday applications. Their use is widespread what makes it a challenge to evaluate the full range of applications and shares (by weight) in associated waste streams.

Compared to other plastics, fluoropolymers are usually used as part of other applications and represent around 0.1% of the total plastics processing demand of the EU countries.

Nevertheless, these plastics, with their unique properties, are high-quality materials where other materials are either inferior or simply do not offer adequate substitutes.

The data and information presented in this report reflect the willingness of the fluoropolymer industry to provide additional end-of-life information on fluoropolymer applications and products in response to requests from EU legislators.

Project frame – 1

Regional focus

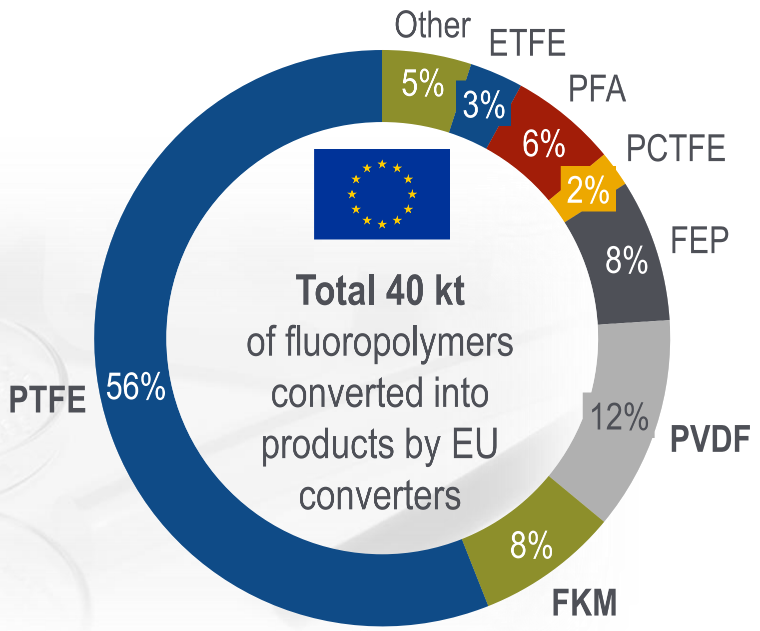
EU27+3 countries (abbreviated by the term “EU” in this report)

Analyzed types of fluoropolymers within this study

- Non-melt processible fluoroplastics, such as PTFE, represent the main focus of the study*
- Thermoplastics such as PVDF
- Elastomers (vulcanized, rubbers) such as FKM

The distribution of FP types shown in the graph on the right is unique for the EU market and differs with regard to individual FP shares in other regions such as North America.

The share of FEP materials used for Local Area network (LAN) cabling (fire resistance) for housing applications in the US is for example significantly higher compared to the EU market.



* almost 90% of all fluoropolymer (and elastomer) processors process PTFE materials for the manufacturing of their products

Project frame – 2

Important applications and origin of fluoropolymers waste

Fluoropolymers provide specific physical and chemical characteristics for wide range of different processes, components and final product applications. The widespread use of fluoropolymers in various applications and industry segments makes it a challenge to evaluate the full extent of fluoropolymer waste origins and corresponding penetration of major waste streams.

This study will focus on six major industries where the use and waste generation of fluoropolymers is considered to be particularly significant.

Within each of the key sector, the specific uses ("applications / products") of fluoropolymers will be identified. For each key sector (based on the corresponding relevant products and applications), this report shows the quantity of fluoropolymers put on the market, different lifetime scenarios and end-of-life treatment of fluoropolymer waste.

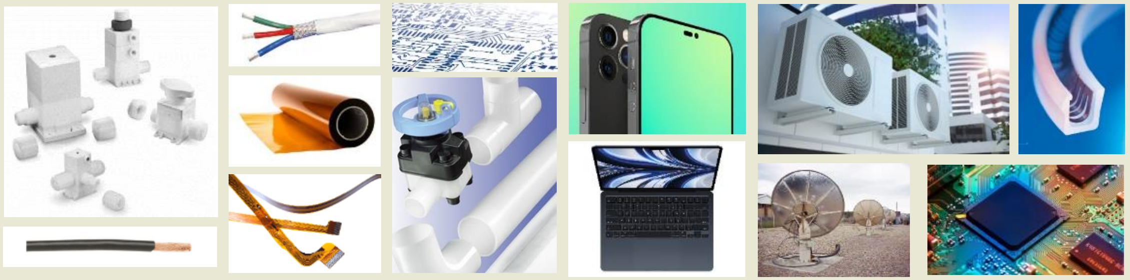
The study will cover the following industry segments:

- Automotive
- Aerospace
- Electronics & semiconductors
- Chemicals (CPI)
- Medical & pharma
- Other (e.g., cookware)

Project frame – 3

Fluoropolymer products and applications in different industry segments – Automotive, Aerospace, Electronics and semiconductors

Major fluoropolymer applications and product illustrations I

Industry segment	Major applications	Fluoropolymer product illustrations
Automotive	Excl. vehicles >3.5 tonnes and other transport segments such as trains and ships ▪ Battery binder, e.g., PTFE and PVDF in EVs ▪ Oxygen sensor parts (wire insulation, grommet and sleeve) ▪ Seals & bearings; fuel and brake system components ▪ Ventilation of electronic housings, gear boxes, lamp housings and batteries using porous PTFE.	
Aerospace	Large and small commercial and private aircrafts, aerospace communication technology and associated aerospace periphery ▪ Cable insulation (tape winding) ▪ PTFE tubing for fuel system & hydraulics ▪ Spring reinforced seals for hydraulic systems ▪ Bearings	
Electronics & semiconductors	Electronic devices of any kind incl. semiconductor manufacturing, communication technology, HVACR, consumer electronics ▪ PCB (printed circuit boards), CCL (copper cladded laminates) ▪ Associated products such as smartphones, tablets, notebooks ▪ Cable insulation, containers, pumps and other (ultra-pure) liquid handling equipment, e.g., in chip manufacturing plants ▪ Seals, valves, tapes used in various HVACR applications	

Project frame – 4

Fluoropolymer products and applications in different industry segments – Automotive, Aerospace, Electronics and semiconductors

Major fluoropolymer applications and product illustrations II

Industry segment	Major applications	Fluoropolymer product illustrations
Chemicals (CPI)	Industry segments chemical, process & industrial incl. petrochemical and energy applications ▪ Pipe liners (e.g., PTFE); lining of valves, pumps (e.g., PFA) ▪ Bellows (flexible vessels), lining of distillation columns, containers for storage and transportation ▪ Hoses, seals, films etc. used for renewable energy applications ▪ Gaskets, filters, membranes, flue gas coolers, etc.	
Medical & pharma	Medical applications and equipment of any kind, pharmaceutical processing equipment ▪ Tubing (e.g., PTFE) ▪ Components for syringes & diaphragms ▪ Components and products for microinvasive surgery ▪ Implants, stents	
Other (e.g., cookware)	Coated consumer & professional cookware, coated sheer metal applications such as building cladding, industrial food & beverage processing equipment, lubricants, architectural and wearable textiles, defence & military applications, renewables like PV and wind power ▪ Coating of pans, pots and trays, sheet metal building cladding ▪ Textiles (wearable) and coated (glass) fabrics (architectural) ▪ Applications not listed in the other industry segments	

Project frame – 5

Fluoropolymer waste in major waste streams – residential, electronics and automotive

Corresponding waste streams I

Waste stream	Definition	Fluoropolymer end-of-life applications
Residential household waste and municipal waste generated by commercial activities	Residential waste collected by or on behalf of municipalities (household waste, excluding all waste fractions which are collected separately) as well as municipal waste generated by commercial activities and other sources, whose activities and waste are similar to those of households (commerce, trade, small business, institutions and municipal services), collected by or on behalf of municipalities	▪ **Other (e.g., cookware)** ▪ Electronics (usually smaller end-of-life consumer electronics)
Electronic waste collection (WEEE)	Waste from electrical and electronic equipment (commonly referred to as WEEE) from households and commercial and industrial (professional WEEE) activities; collected on behalf of municipalities, retailers and private organizations	▪ **Electronics & semiconductors**
ELV incl. auto-shredder residue (ASR)	Plastic waste through dismantling of end-of-life vehicles (ELVs) and plastic residual fractions as part of metal shredding processes in auto-shredder residue respectively shredder-light-fraction	▪ **Automotive**

Project frame – 6

Fluoropolymer waste in major waste streams – commercial and industrial

Corresponding waste streams II

Waste stream	Definition	Fluoropolymer end-of-life applications
Commercial & industrial Various waste streams collected (mostly) on behalf of private waste management companies respectively dedicated waste services for specific industries. ▪ Description of relevant fluoropolymer waste streams as far as possible (e.g., extraction of fluoropolymer pipe liners from chemical process equipment)	Commercial & industrial waste generated, collected, sorted, treated and disposed of by private waste management companies, e.g., waste services for chemical and pharmaceutical industries, energy sector (power plants), food and beverage industry, building and construction applications, medical applications, aerospace applications, car repair shops, as well as all remainder products and applications not collected in residential household waste and municipal waste generated by commercial activities, WEEE and ELV waste streams	▪ **Automotive** ▪ **Aerospace** ▪ **Electronics & semiconductors** ▪ **Chemicals (CPI)** ▪ **Medical & pharma** ▪ Other (e.g., professional cookware)

Project frame – 7

Waste treatment

Recycling, Energy Recovery, Landfill

Waste treatment	Definition
Recycling	▪ Physical material processing of fluoropolymers waste into regrind and recycled granules and compound materials ▪ Recycling of pre- and post-consumer fluoropolymer waste. Thermoplastic fluoropolymer supply for recycling primarily from industrial applications such as semiconductor process equipment or from chemical and pharmaceutical end-of-life applications. ▪ As most fluoropolymers (and elastomers) are not melt-processable such as thermoplastics, the term recycling in this report includes mechanical recycling and other recycling technologies such as regrind and sintering as well as chemical recycling.
Incineration for heat / electricity utilization (Energy recovery)	▪ Waste incineration for energy recovery purposes in MSWI plants (municipal solid waste incineration), SRF / RDF (solid recovered fuel / refuse derived fuel) power plants or cement kilns (e.g., rotary kilns) and hazardous waste incineration plants (e.g., for hospital waste). ▪ The average calorific value of some FP waste fractions such as PTFE is typically lower compared to other plastics such polyolefins. However, the usually small shares of fluoropolymers within a mixed waste fractions send to MSWI plants have no significant effect on the overall waste-to-energy performance. ▪ Please note, that this report does not provide detailed information about average operative incineration temperature levels. A further analysis of existing exhaust gas treatment systems is also not part of this report.
Landfill	▪ Waste treatment on a landfill sites for the disposal of waste fractions ▪ The EU landfill directive defines the different categories of waste (municipal waste, hazardous waste, non-hazardous waste and inert waste) and applies to all landfills, defined as waste disposal sites for the deposit of waste onto or into land. ▪ Typically, fluoropolymer waste is chemically inert.

Project frame – 8

Target companies

End-of-life fluoropolymer applications and relevant players along the waste chain

	Large shredder facilities	WEEE dismantlers	Waste management companies	Metal recyclers	Industrial service companies	Hospitals	Aircraft dismantlers	Municipal waste services	Internal service / maintenance
Automotive	✓		✓	✓					
Aerospace				(✓)			✓		
Electronics & semiconductors	✓	(✓)			(✓)		(✓)		
Chemicals (CPI)			✓	(✓)	✓			(✓)	✓
Medical & pharma			✓			✓		(✓)	✓
Other (e.g., cookware)	✓	✓	✓	(✓)				✓	

CONVERSIO Market & Strategy

Main objective, key questions and targets – 1

The main objective of the project was to further determine and define the main applications and products, where fluoropolymers are used and to understand what happens to those applications at the end of their life. A correlation matrix between fluoropolymer applications and the penetration of relevant waste streams (by mass in kt and %) was developed and the waste treatment route (recycling, energy recovery and landfill) is shown.

This report delivers an in-depth description on how and where fluoropolymer containing products and corresponding wastes are generated and what happens to the collected fractions at the end of their life. Quantities of fluoropolymer waste are included as far as possible based on an end-of-life fluoropolymer (and relevant fluoropolymer containing products) lifetime assessment model. This report has qualitative and quantitative character.

The main scope of the report can be summarized as follows:

- Identification where fluoropolymer applications and products end up at the end of their life including re-use of processing scrap and recycling of either pre- or post-consumer fluoropolymer waste (either mechanical, e.g., conversion into PTFE micro powders or chemical) in the EU.
- Identification of major waste streams in which the fluoropolymer applications and products end up incl. total volumes in kt as well as the penetration of fluoropolymers (in kt and %) in the EU.

Main objective, key questions and targets – 2

The report has a semi-quantitative character with additional supplemental qualitative case studies for specific waste streams and applications providing further information about the fate of fluoropolymer-relevant applications at their end-of-life.

This report provides…

- information on where the fluoropolymer applications end up at the end of their life and in which waste streams,
- data about the quantities of different waste streams with a model-based estimation about the expected fluoropolymer penetration,
- a general overview for the treatment of relevant waste streams and where included end-of-life fluoropolymers applications end up or are co-treated as part of commingled fractions (e.g., metal recycling, waste incineration, landfill, etc.),
- information about collection and treatment opportunities of fluoropolymer associated products in terms of circularity,
- additional knowledge on the treatment of pre-consumer fluoropolymer processing waste of fluoropolymer product manufacturers.

Analysis of end-of-life fate of fluoropolymers within…

- different applications
- different products
- corresponding waste streams

Methodology and data model – 1

Structure of the fluoropolymer flow analysis

- Identification and assessment of pre-defined fluoropolymer applications and corresponding products within the applications Automotive, Aerospace, Electronics & semiconductors, Chemicals (CPI), Medical & pharma and Other (e.g., cookware)
- Description and assessment of the end-of-life fate of different fluoropolymer associated applications and products
- Model calculation of corresponding waste streams and their treatment, including fluoropolymer shares

Data model approach

- Identification of major fluoropolymer-relevant products and applications in different industry segments
- End-of-life analysis of fluoropolymer products based on individual EOL scenarios, e.g., by average lifetimes of fluoropolymer products and applications
- Modeling of fluoropolymer waste collection data for the main industry segments and applications considering the dated back FP market volumes for a calculation of the total EU fluoropolymer waste in 2020 incl. continuous plausibility checks
- Identification of relevant waste streams and the different waste treatment routes (recycling, incineration, landfill)
- Estimation of the fluoropolymer penetration and (co-)treatment routes within the different waste streams
- Discussion of preliminary results with the Fluoropolymer project group and preparation of a final model calculation and reporting

Methodology and data model – 2

Multimethodological approach

Secondary research

Comprehensive analysis of information and data from **external databases and secondary research sources**

Incl. reports from environmental agencies, official statistics and databases, fluoropolymer manufacturer datasheets, academic journals, information from associations, etc.

Conversio own databases

Analysis of existing knowledge including data transfer, validation and reframing from previous reports, e.g., EU Circular Economy 2020 report or Post-consumer fluoropolymer report 2019

Incl. analysis of existing model calculations in with regard to individual lifetime and waste collection scenario incl. validation and reframing of existing knowledge together with new insights.

Analysis of data from different information sources, elaboration of a data model, validation and reporting

Primary research

Interviews with quantitative and qualitative questions in Europe with fluoropolymer product manufacturers, waste generators, waste management companies, shredder facilities, WEEE dismantlers, etc.

- The project methodology is based on a **semi-quantitative, multi-methodological approach.**
- Generally, for application and industry segment shares, average lifetimes and fluoropolymer waste collected in different waste streams, information from **several information sources** has been used such as data and information from official production and waste statistics, Conversio own reports and databases, interviews with industry experts along the fluoropolymer value chain as well as further secondary research sources.

Methodology and data model – 3

Data model

Where a calculation on individual fluoropolymer EOL product scenarios was insufficient, a data extrapolation was performed, e.g., for the large number of different commercial & industrial applications.

	①	②	③
Topic	**FP products & applications** Interviews with fluoropolymer product manufacturers and harmonization with existing data and calculations	**LCA model for individual FP products** EOL analysis of major FP products in different industry segments	**FP waste analysis** Alignment of dated back FP market volumes, LCA assumptions and interview results
Result	**FP put on the EU market in 2020** FP market volumes per industry segment and application; estimation market shares by FP types	**Lifetime model for FP applications** EOL FP data model by average lifetime in years incl. dated back FP market volumes per application	**EU FP waste in 2020** FP waste volumes per waste stream and industry segment incl. waste treatment routes

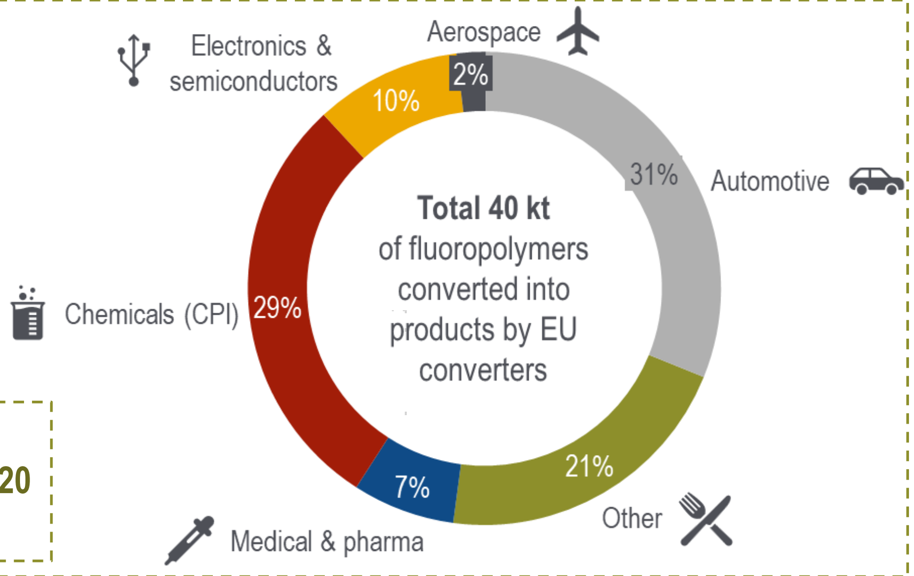
Secondary research + Primary research + Plausibility checks

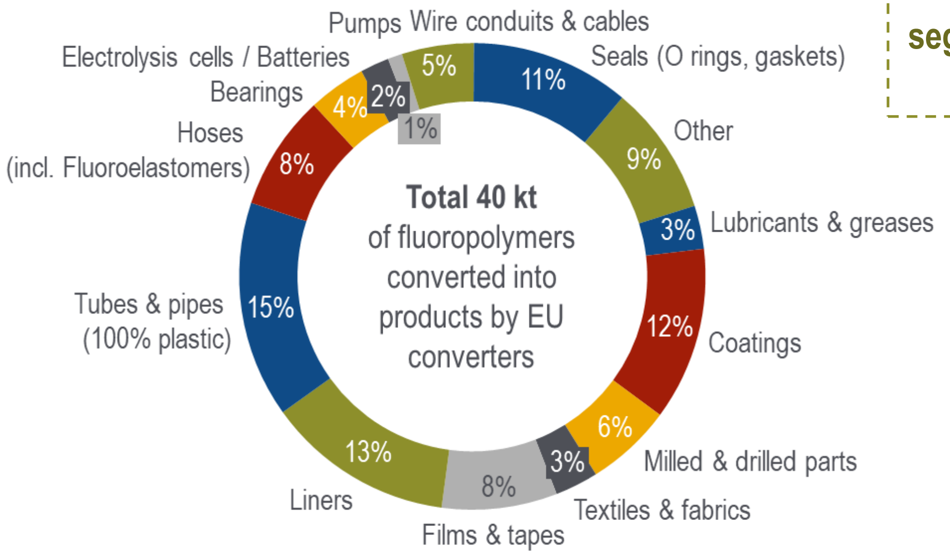
Agenda

Management Summary I

- In 2020 about 40 kt of FP materials were sold to European FP product manufacturers. The largest share accounted for PTFE materials (~56%) followed by PVDF (~12%), FKM (~8%) and FEP (~8%).
- By view of FP product manufacturers, tubes & pipes (~15%) followed by liners (~13%), coatings (~12%) and Seals (~11%) were the most relevant FP applications.
- The most relevant industry segments were Chemicals (~29% incl. Energy), Automotive (~31%) and Others (~21% incl. coated metals, cookware, lubricants, textiles, Food & beverage etc.).

Fluoropolymer market by industry segments & products / applications 2020
Shares based on quantity in kt



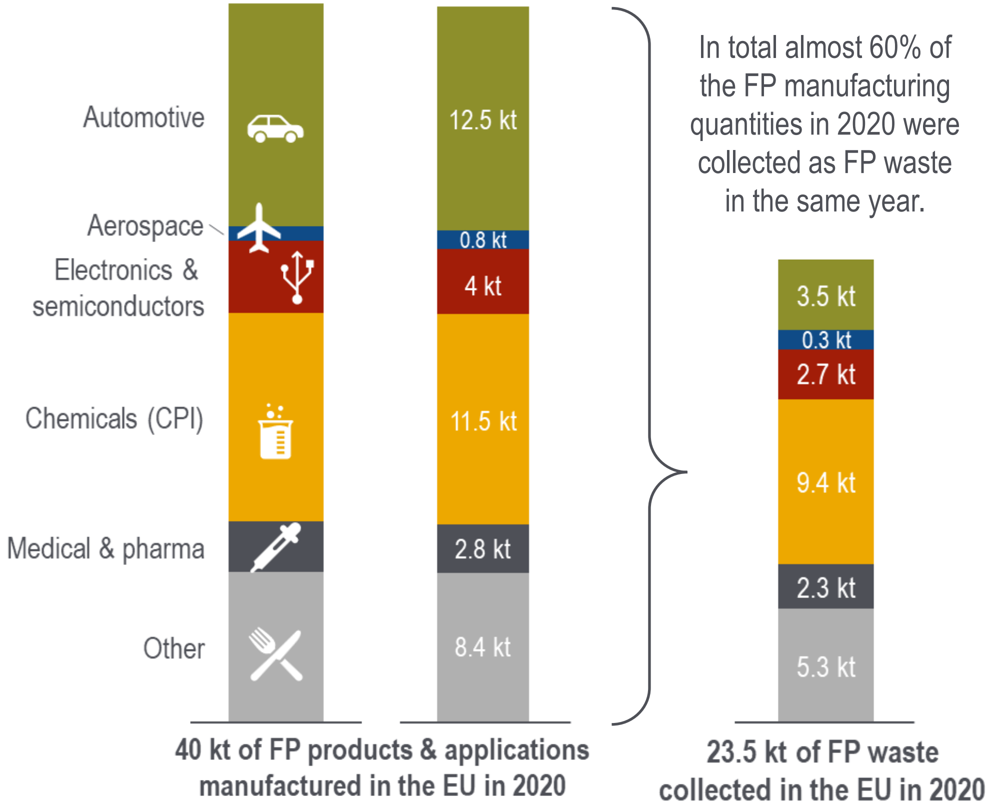


- The data for FP materials used by manufacturers (i.e., FP materials sold) in the European market was aligned with the report* by the Wood Group on behalf of PlasticsEurope in 2022.
- Based on the Wood Group report, the quantity of FP materials sold in Europe declined by around 23% from 52 kt in 2015 to 40 kt in 2020 due to lower import volumes, the pandemic situation, raw material price increases and data model adaptions.
- In total, about 49 kt of FP raw materials were produced in the EU in 2020, making the EU a net exporter of FP raw materials (export surplus).

* Update of market data for the socio-economic analysis (SEA) of the European fluoropolymer industry (Wood Group UK Limited; May 2022)

Management Summary II

- In 2020, around 23.5 kt of FP waste were collected* via different residential as well as commercial and industrial waste streams.
- Applications with typically longer lifetimes accounted for the larges share of FP materials used. Accordingly, the backdated FP volumes which were, for example, used in a passenger car or aircraft 20 years ago were significantly lower which results in a gap between FP manufacturing and waste quantities in the same year.

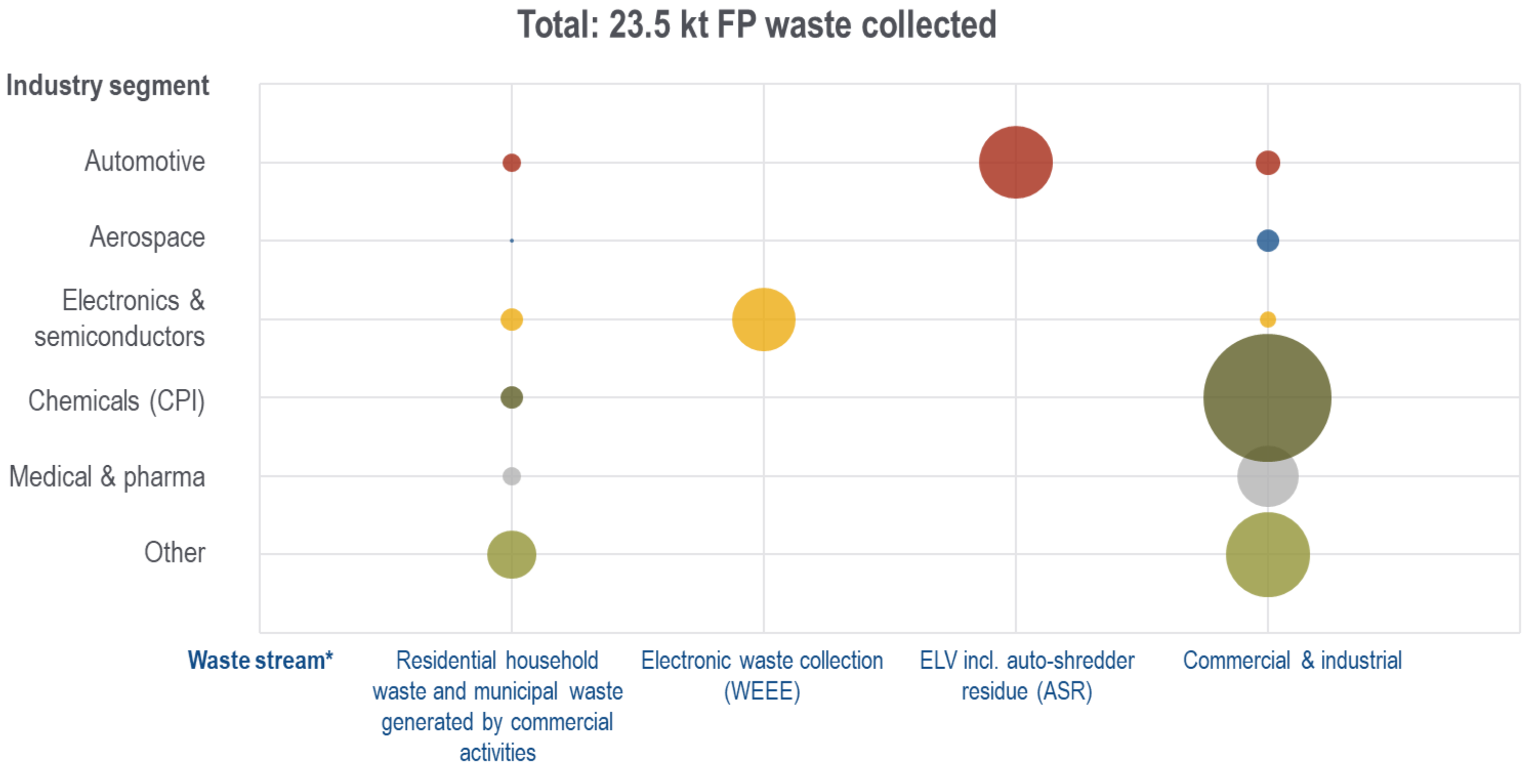


- Additional reasons for a gap between FP manufacturing quantities and collected waste are statistical gaps of reported end-of-life vehicle figures in Europe. According to the Heinrich Böll Foundation's European Mobility Atlas 2021, around 12 million cars leave European roads, but only about half of these are handled in authorised recycling facilities respectively are recorded by official statistics.
- In addition, the EU is a net exporter of many FP based products, incl. industrial production and processing equipment, passenger cars, aircrafts or medical and pharma applications. The export surplus resulted in lower quantities of FP products and applications being put on the market compared to FP products and applications being manufactured.
- Compared to the 2017 figures, where about 22.9 kt of FP waste were generated and 19.7 kt were officially collected, the amount of FP waste collected in 2020 slightly increased.
- For the calculation of FP waste collected in 2020, additional new insights and an extended research scope (e.g., through maintenance measures of transport applications) were taken into account.
- Pre-consumer process losses of FP product manufacturers accounted for around 20% or ~8 kt in 2020.

* Waste generation and waste collection often slightly differ. For example if an EU end-of-life aircraft or ship is dismantled in extra-EU countries.

Management Summary III

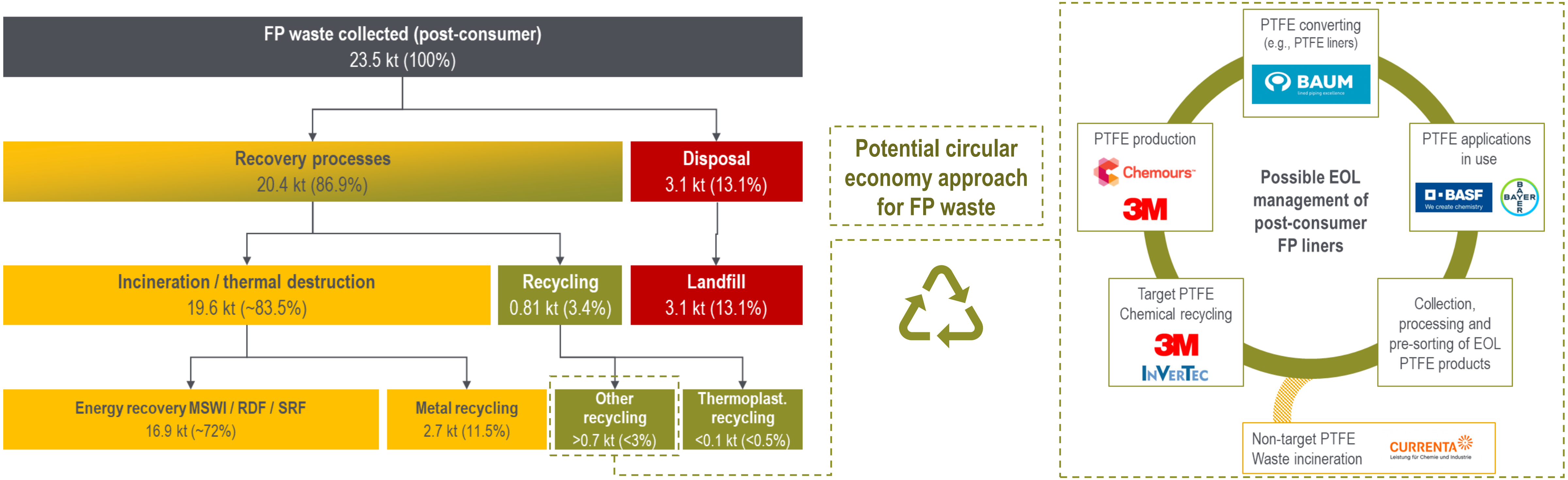
- The most relevant waste streams for the collection of end-of-life FP applications are commercial and industrial waste streams, which are usually collected by private waste management or industrial service companies.
- Only a small proportion of FP waste is collected in residential or private waste streams, such as mixed residential waste, which is often collected on behalf of municipal waste collection services.



- Commercial and industrial waste streams mainly cover end-of-life FP production and processing equipment from (petro-)chemical and pharmaceutical companies, food & beverage producers, the semiconductor industry or the energy sector.
- Significant volumes of FP waste are also collected in electronic waste (WEEE) or ELV waste.
- Large shredder facilities often process ELV wrecks and larger end-of-life appliances within the same waste stream and lighter materials such as plastics (incl. FP) are sorted out in a shredder-light fraction.

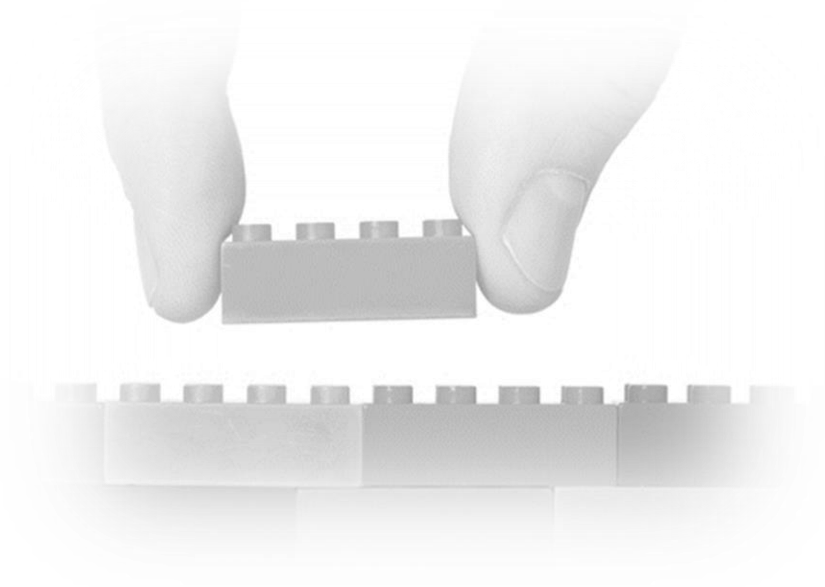
Management Summary IV

- In total, about 23.5 kt of FP waste were collected in 2020, which is less than 0.01% of the total waste collection (615,000 kt). In comparison, around 29,450 kt of plastics were collected in 2020 (<5% of the total waste collection excl. mineral fractions).
- Almost 84% (or 20.4 kt) of the total FP waste collected in Europe in 2020 is either (co-)incinerated or thermally destructed. Around 3.1 kt or slightly over 13% of the total FP waste collected were sent to landfill sites.
- Slightly more than 0.8 kt were collected separately for recycling and a significant proportion of this was exported for recycling, e.g. to Asian countries.



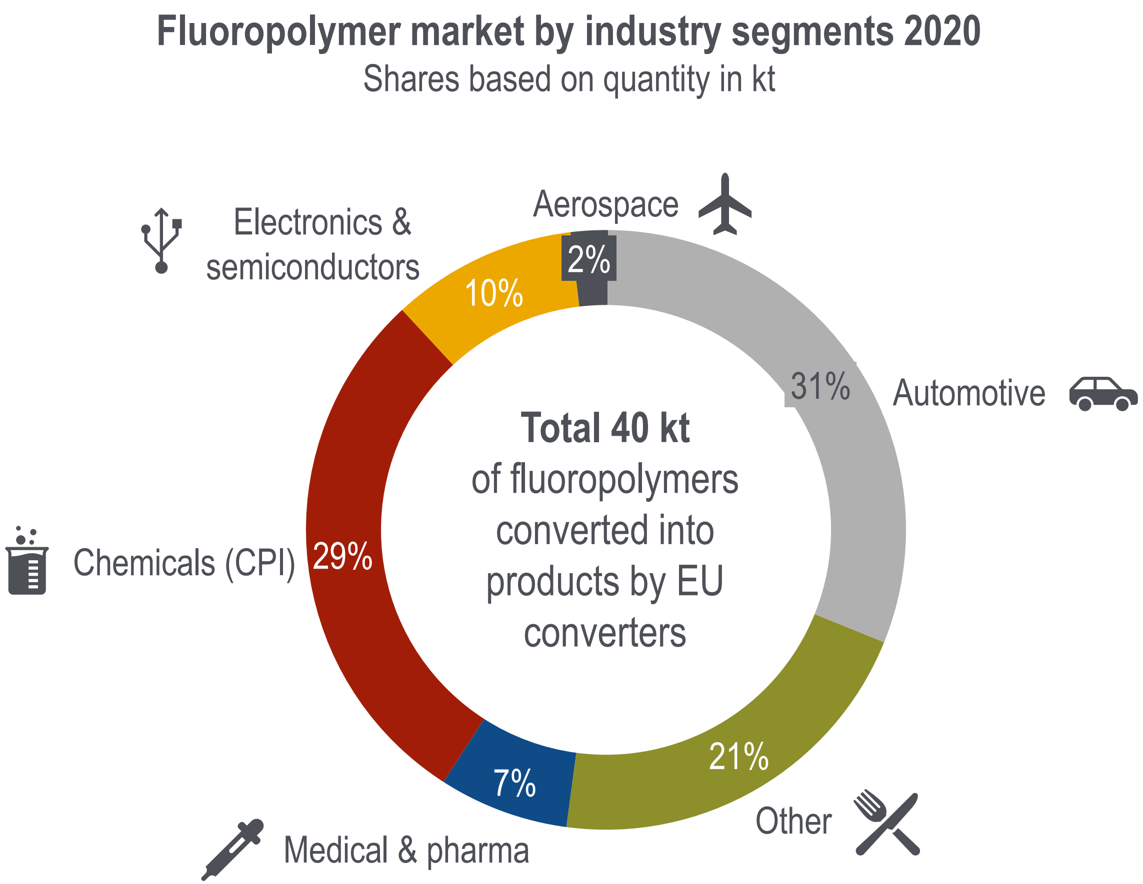
At a glance

- In 2020, around 40 kt of fluoropolymer materials were sold to EU fluoropolymer product manufacturers. 23.5 kt of fluoropolymer waste were collected, either in commingled waste streams or partly in source separated waste fractions.
- Almost 84% of all fluoropolymer applications were incinerated at the end of their life in energy recovery (MSWI ~72%) or thermal destruction (metal recycling ~12%) processes. 13% of the collected fluoropolymer waste was landfilled and around 3% was recycled.
- End-of-life fluoropolymer production and processing equipment used for different industrial segments, such as Chemical, Energy, Food & beverage, Pharma and Semiconductor accounted for the major share of the total fluoropolymer waste quantity collected (~13 kt).
- The overall fluoropolymer penetration in all waste streams was less than 0.01% by weight. In comparison, plastics in total accounted for about 4.8% of the total waste collection volume (excl. mineral fractions).
- Chemical recycling of fluoropolymer waste offers the opportunity to produce virgin-like fluoropolymer raw materials for the production of goods and products without quality limitations. However, building robust supply chains for large-scale and economical feasible recycling processes is one of the most important issues to be addressed in the coming years.



Agenda

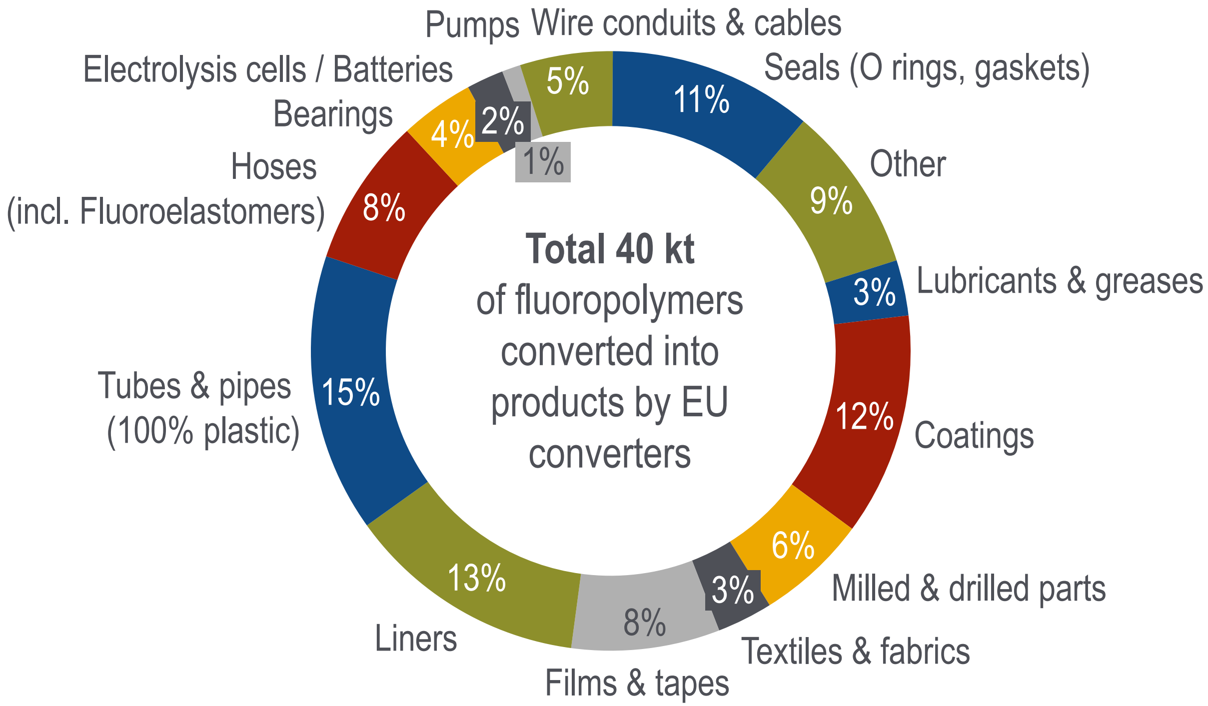
Converting of fluoropolymer materials in EU in 2020 – by industry segments



- Around 12 - 13 kt of FP materials were used for the production of automobiles and associated spare parts. Modern cars use around 0.6 up to 0.8 kg of FP materials to cope with the tighter emission regulations and the growing importance of sensor, communication, safety and comfort systems.
- In addition, EVs use PVDF electrode binders and separator coatings in their battery systems improving the overall battery performance and long-term reliability of the battery system.
- The chemical industry together with the petrochemical and energy industry (incl. renewables) accounted for almost 30% of all FP products and applications manufactured in the EU. Relevant applications are for example liners for pipes, pumps and vessels or FP gaskets, tubing, bellows, flue gas treatment / cooling systems and various other products.
- Medical applications, such as syringes, tubing, pipes, milled & drilled lab equipment, diaphragms or microinvasive surgery applications, such as stents, account for around 2 - 3 kt of FP materials used for manufacturing.
- Electronics & semiconductors also include electronic devices such as smartphones, tables and notebooks incl. the associated infrastructure for long distance communication such as antennas.
- Other applications account for around 7 - 8 kt of FP materials used in 2020, incl. ~5 kt for coated metals incl. consumer cookware (>2 kt).

Converting of fluoropolymer materials in EU in 2020 – by products & applications

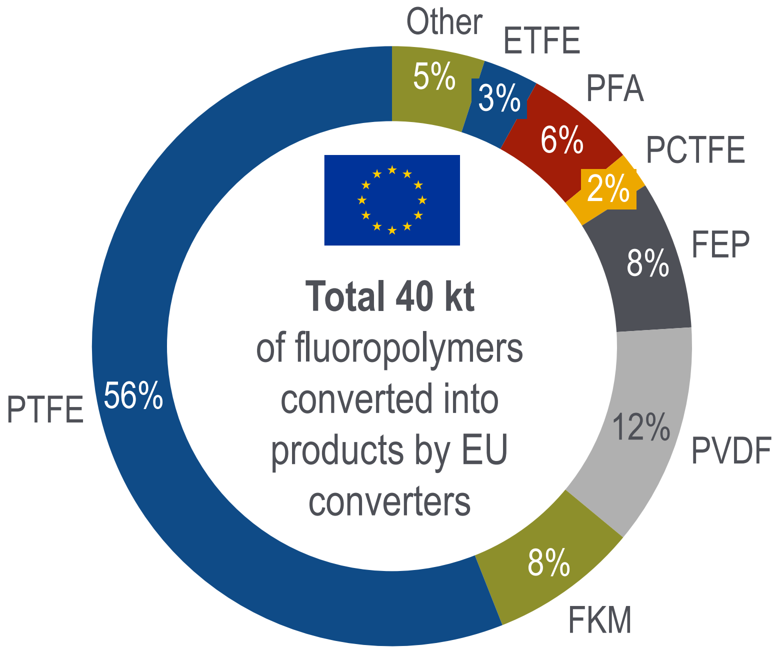
Fluoropolymer market by products & applications 2020
Shares based on quantity in kt



- The split into different FP products & applications was based on survey results with more than 20 different FP product manufacturers in the EU.
- The three FP application and product categories Tubes & pipes (100% FP materials), liners (e.g., for corrosion prevention of steel pipes) and seals (incl. O rings and gaskets accounted for around 40% (or 15 - 16 kt) of the total FP materials processed in the EU in 2020. Coatings for coils / sheet metal, pans, pots, etc. account for about 5 kt.
- The category textiles & fabrics includes wearable FP (membrane) materials for outdoor clothing as well as protective clothing for professional tasks such as firefighter coats. This category also includes glass coated fabrics used for architectural and industrial applications.
- The category Other includes, for example, other additives, compounding with engineering polymers, as well as various other smaller applications such as bellows, membranes, etc.
- Lubricants & greases include dry FLP lubricants or FP additives for lubricants / greases.

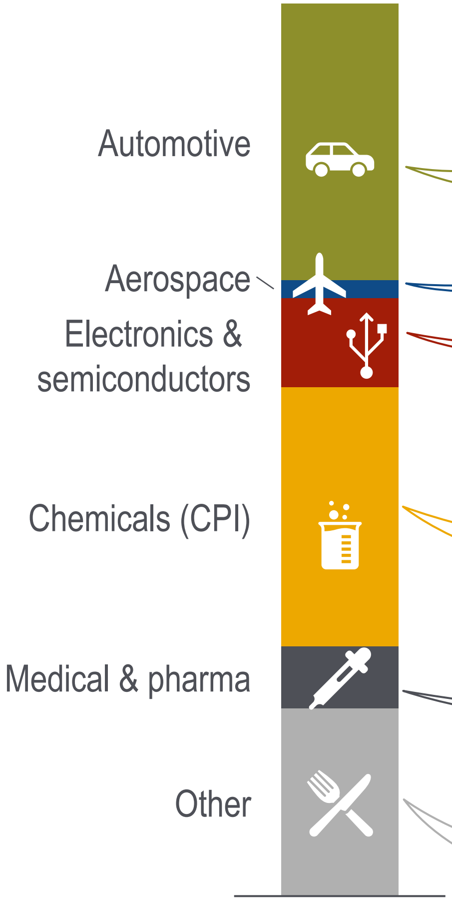
Converting of fluoropolymer materials in EU in 2020 – by FP types

Fluoropolymer market by polymer & elastomer types 2020
Shares based on quantity in kt



- Around 50 - 60% of the EU 2020 FP market accounted for PTFE based products & applications for different industry segments.
- PTFE is a not melt-processable thermoplastic resin with duroplast characteristics and therefore not suitable for mechanical recycling processes, which are usually used for thermoplastic materials such as for example polyolefins. Fluoroelastomers, such as FKM, are also not suitable for mechanical plastic recycling processes.
- Chemical recycling provides an opportunity to recycle pre- and post-consumer PTFE materials into a virgin material qualities.
- Opened in 2015, a chemical pilot recycling plant located in Burgkirchen (Germany) by 3M (former Dyneon) shows that the recycling of non-melt-processable FP is possible. The existing plant is capable of recycling up to 500 t of FP materials per year.
- In addition, pre- and post-consumer PTFE is for example thermo-mechanically recycled into micro-powders.
- FP materials, such as PVDF or PFA, are technically suitable for conventional mechanical recycling processes.

Fluoropolymers quantities by industry segment in the EU in 2020 – long lifetimes, export surplus and export of used cars and electronics



40 kt of FP products & applications manufactured in the EU in 2020

FP products manufactured by EU companies are mainly used for applications that have longer lifetimes and often for products that have high export surplus rates.
Compared to other materials such as polyolefins or PET, which are aften used in short-life (<1 year) packaging applications, FP materials are predominantly used for technical applications.

12.5 kt (Automotive)

Export surplus of new cars and associated parts. In general low service requirements of FP affiliated parts. Typical age of an ELV around 12 years + approx. 60 g of FP materials replaced via maintenance. **Export surplus of used and deregistered cars** to countries outside the EU.

0.8 kt (Aerospace)

Export surplus of new aircrafts and associated parts. D-check maintenance of commercial aircrafts in use every 12 years incl. exchange of (at least partly) FP fuel and hydraulic system parts.

4 kt (Electronics & semiconductors)

Usually **lifetimes of 10 - 20 years** for processing equipment. Lifetimes of consumer electronics between 3 - 10 years. **Export surplus of used electronics** outside the EU.

11.5 kt (Chemicals (CPI))

Average **lifetimes** of liners and other affiliated FP products used for chemical production processes between **10 - 20 years**. Range from 1 year, e.g., for high-purity applications and very aggressive substances and demanding production environments **up to 50 years** for tubes and pipes used for less aggressive substances and less demanding production environments. **Possibility to improve recycling**, e.g., of liners previously used for corrosion prevention.

2.8 kt (Medical & pharma)

Average **lifetimes** of FP pharma processing equipment of around **5 - 15 years**. Medical FP applications range from short life single-use products, e.g., sterile syringe filters up to several decades for PTFE covered stents.

8.4 kt (Other)

Lifetimes of ,e.g., PTFE coated pots and pans on average 4 - 5 years other transport applications 15 - 25 years, architectural fabrics up to 20 years, processing equipment in the food and beverage industry 5 - 15 years, etc.

Fluoropolymers quantities 2015 vs. 2020

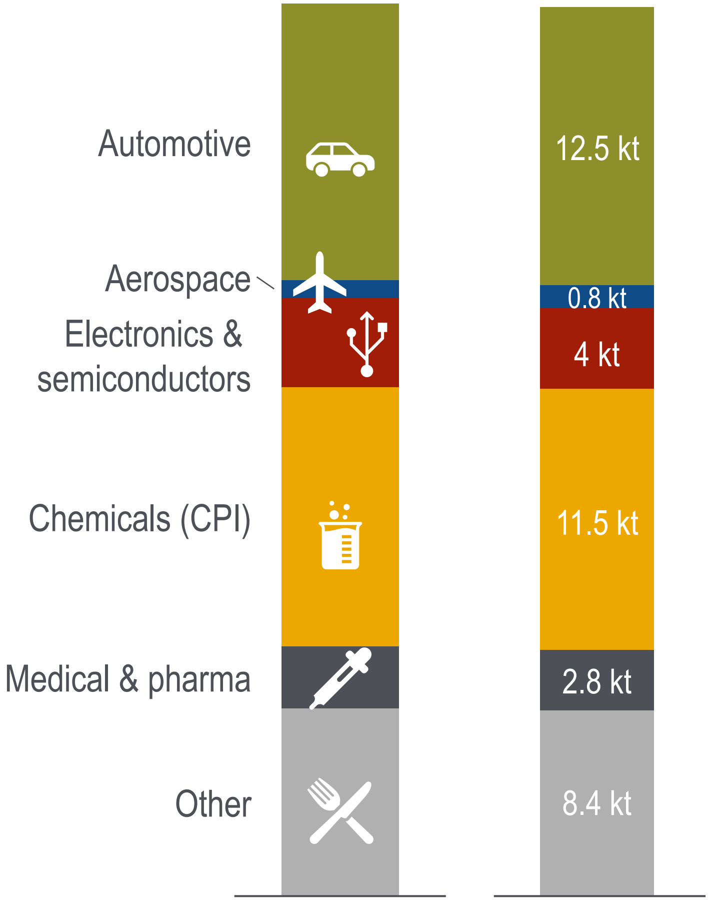
FP raw materials sold to the EU FP product manufacturers – export and import adjusted

Sector	2020 FP quantity sold in the EU in kt	2015 FP quantity sold in the EU in kt
Chemical & Power	10 - 12	16.5
Food & Pharma	2	3
Electronics	3.5	3.5
Transport	15.5	18.5
Renewable energy	0.5	0.5
Cookware	2	3.5
Medical	0.5	1.5
Textiles & architecture	1.5	3
Other	3	2
Total	**40**	**52**

- The data for the FP materials used by manufacturers (i.e., FP materials sold) in the EU market was aligned with the Wood Group report "Update of market data for the socio-economic analysis (SEA) of the European fluoropolymer industry" on behalf of PlasticsEurope in 2022.
- The authors noted that the data presented in their latest report covers a high market share (i.e., higher number of participants) and was not extrapolated compared to 2015 data, which was extrapolated.
- According to the report the major reasons for the decline from 52 kt of FP materials sold in 2015 compared to 40 kt in 2020 were a result of lower import quantities and the overall production drop in various industries due to the pandemic situation. The increase of FP raw material prices was also stated as a reason for the lower FP quantities in 2020.
- The data used in this report was aligned to the data published on behalf of PlasticsEurope, but slightly adapted to a different industry segmentation focus.
- In total, about 49 kt of FP raw materials were produced in the EU in 2020, making the EU a net exporter of FP raw materials (export surplus).

Agenda

Fluoropolymers quantities by industry segment in kt – differences between FP products manufactured and FP waste collected in the EU in 2020



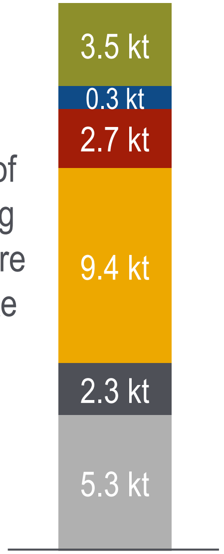
40 kt of FP products & applications manufactured in the EU in 2020

FP quantities manufactured vs. FP waste collected

The differences between FP manufactured products & applications and FP waste collected in different waste streams in the same years is a result different measures:

- *export-import balance of manufactured products,*
- *LCA (average lifetimes) of different FP associated products and applications,*
- *dated-back FP volumes in total an per industry segment over the last 30 years,*
- *maintenance measures of FP associated products and applications in use,*
- *export-import balance of used products (e.g., cars exported for second use outside the EU),*
- *official waste statistics (i.e., waste collected) – often not a 100% coverage of all waste arisings (i.e., waste generated) incl. statistical gaps, e.g., unknown whereabouts of ELVs, etc.,*
- *continuous adjustments through additional information by waste management companies, waste producers and existing Conversio internal databases and reports.*

In total almost 60% of the FP manufacturing quantities in 2020 were collected as FP waste in the same year.



23.5 kt of FP waste collected in the EU in 2020

FP waste collection by industry segment in the EU in 2020

Collected FP waste by industry segment in the EU in 2020

Industry segment	Collected FP waste in kt
Automotive	3.5
Aerospace	0.3
Electronics & semiconductors	2.7
Chemicals (CPI)	9.4
Medical & pharma	2.3
Other	5.3
Total	**23.5**

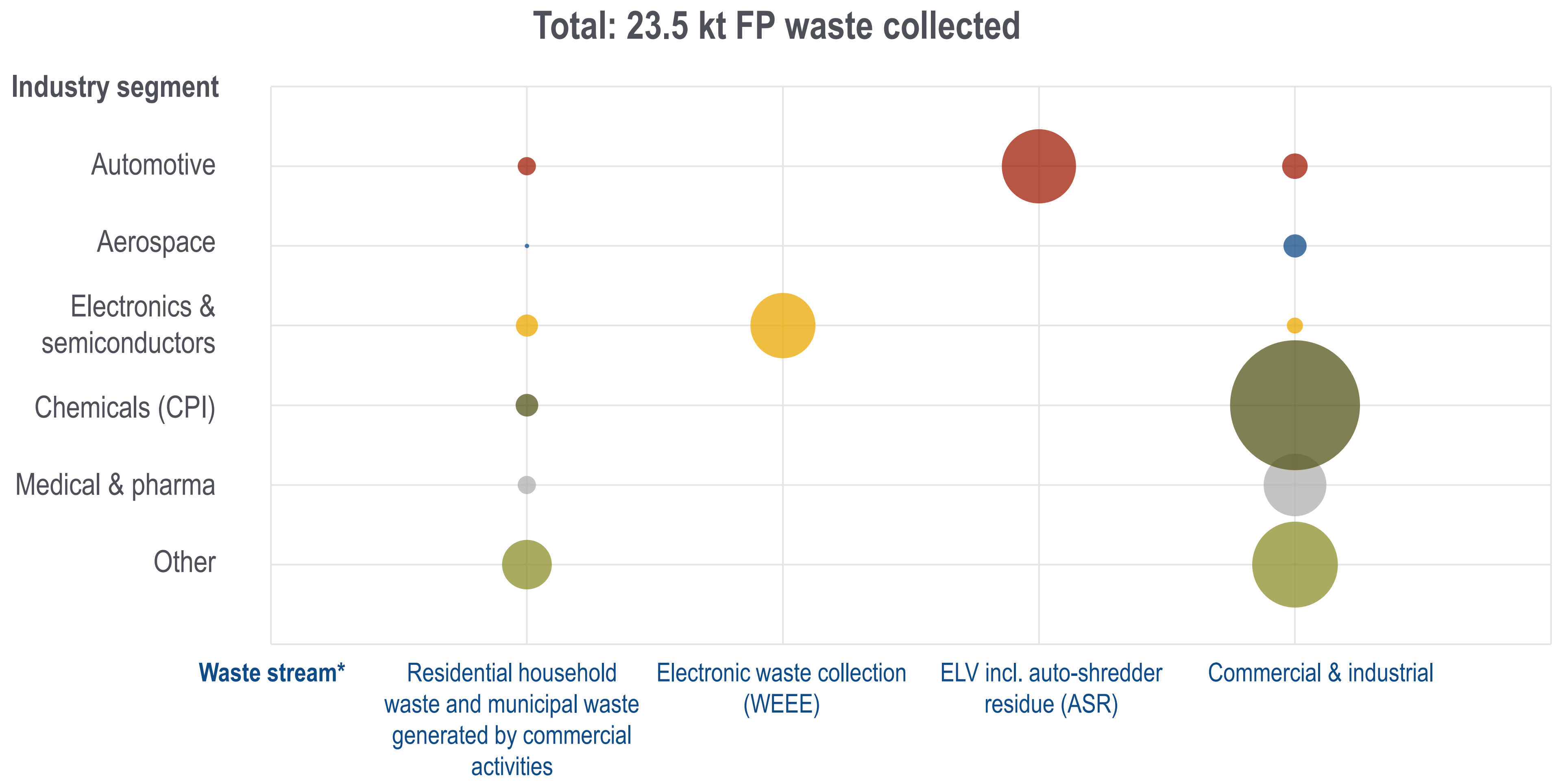
- In total, around 23.5 kt of FP waste were collected in different industry segments in the EU in 2020.
- In 2017 around 22.9 kt of FP waste were generated and 19.7 kt were officially collected.
- For the calculation of FP waste collected, additional new insights and an extended research scope (e.g., through maintenance measures of transport applications) were taken into account.
- Statistical gaps between officially collected waste and waste generated still exist and will be described in more detail in the individual case studies.
- One example is the number of officially treated end-of-life vehicles: According to the Heinrich Böll Foundation’s European Mobility Atlas 2021, around 12 million cars leave European roads due to total loss after an accident, economic write-off, non-compliance with new safety or emissions standards or a change in design preferences – but only around half of them are handled in authorised recycling facilities respectively are recorded by official statistics.

Waste collection by waste stream in the EU in 2020 – total, plastics, fluoropolymers

Collected FP waste by waste stream in the EU in 2020

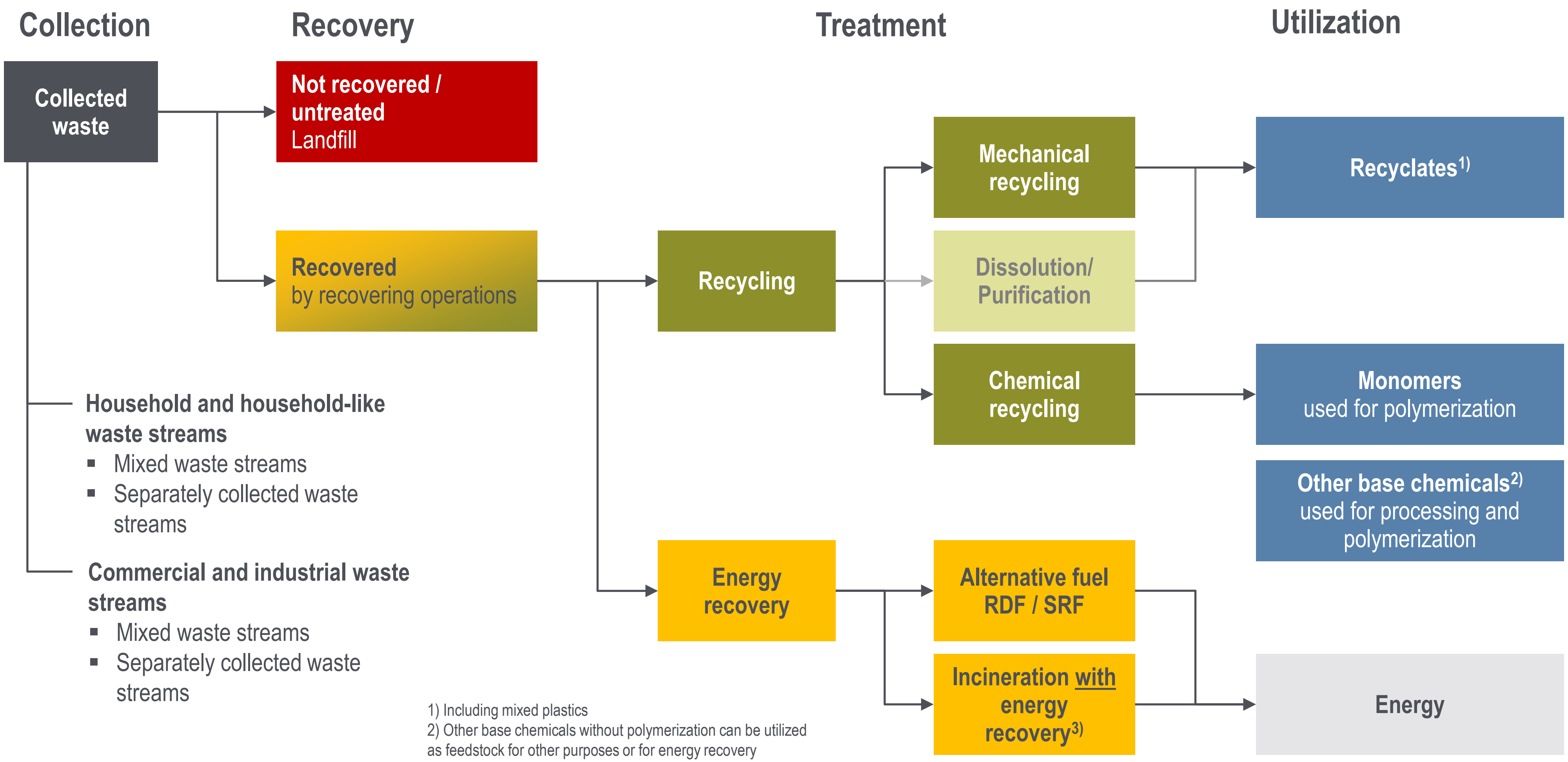
FP relevant waste stream	Total waste collected in kt	Thereof plastics in kt	*Share in %*	Thereof FP in kt	*Share in %*
Residential household waste and municipal waste generated by commercial activities	148,500	10,300	*6.9*	2.2	*<0.01*
Electronic waste collection (WEEE)	5,000	1,170	*23.4*	2.3	*0.05*
ELV incl. auto-shredder residue (ASR)	10,000	1,190	*11.9*	3.0	*0.03*
Commercial & industrial (various streams; usually commingled)	400,000	4,700	*1.2*	15.1	*<0.01*
Total	**563,500**	**17,360**	***3.1***	**23.5**	***<0.01***
Other waste streams not further analysed / relevant e.g., separate collection of LWP waste or separate collection of commercial packaging waste	*51,500*	*12,090*	*23.5*	*<1 kt*	*<0.01*

Graphical illustration of FP waste collected by industry segment and waste stream



*excl. 'Other waste streams not further analysed / relevant'

Waste stream flow chart – collection, treatment and utilization



1) Including mixed plastics
2) Other base chemicals without polymerization can be utilized as feedstock for other purposes or for energy recovery
3) Incineration with „Energy-from-waste (EfW)“

Circular economy illustration for fluoropolymers

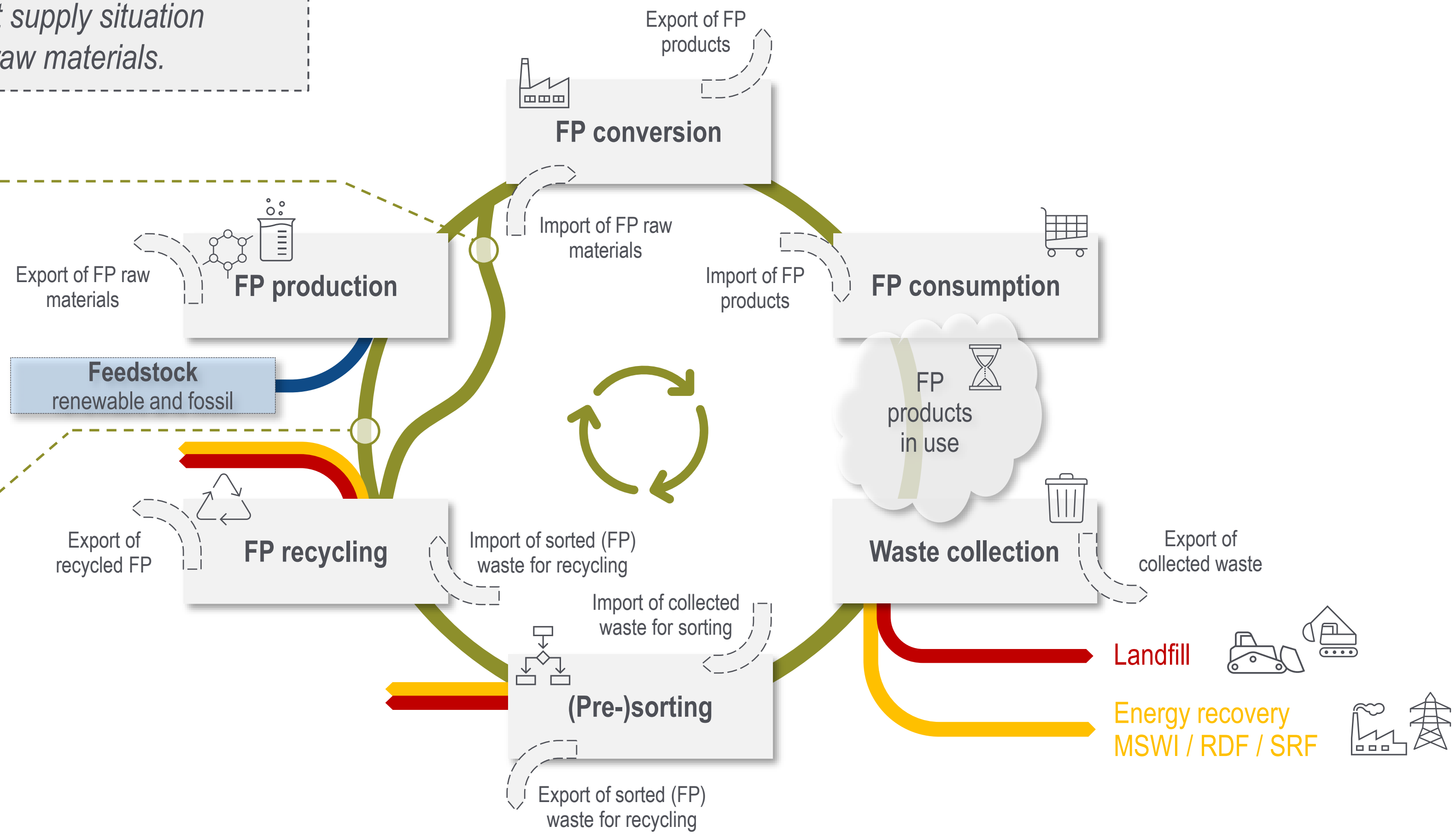
Fluorspar / calcium fluoride (CaF_2) is a limited resource. The circularity of FP materials could offer a way to cope with the growing market demand for FP materials and the tight supply situation (import dependency) for relevant secondary raw materials.

Mechanical recycling of FP

- Melt-processable FP such as PVDF or PFA
- Re-grind and processing of not melt-processable FP materials into powders etc.

Chemical recycling of FP

- 3M recycling plant for not melt-processable FP materials
- Virgin-like raw material quality for the manufacturing of new FP products & applications



Treatment of FP waste by industry segment in the EU in 2020

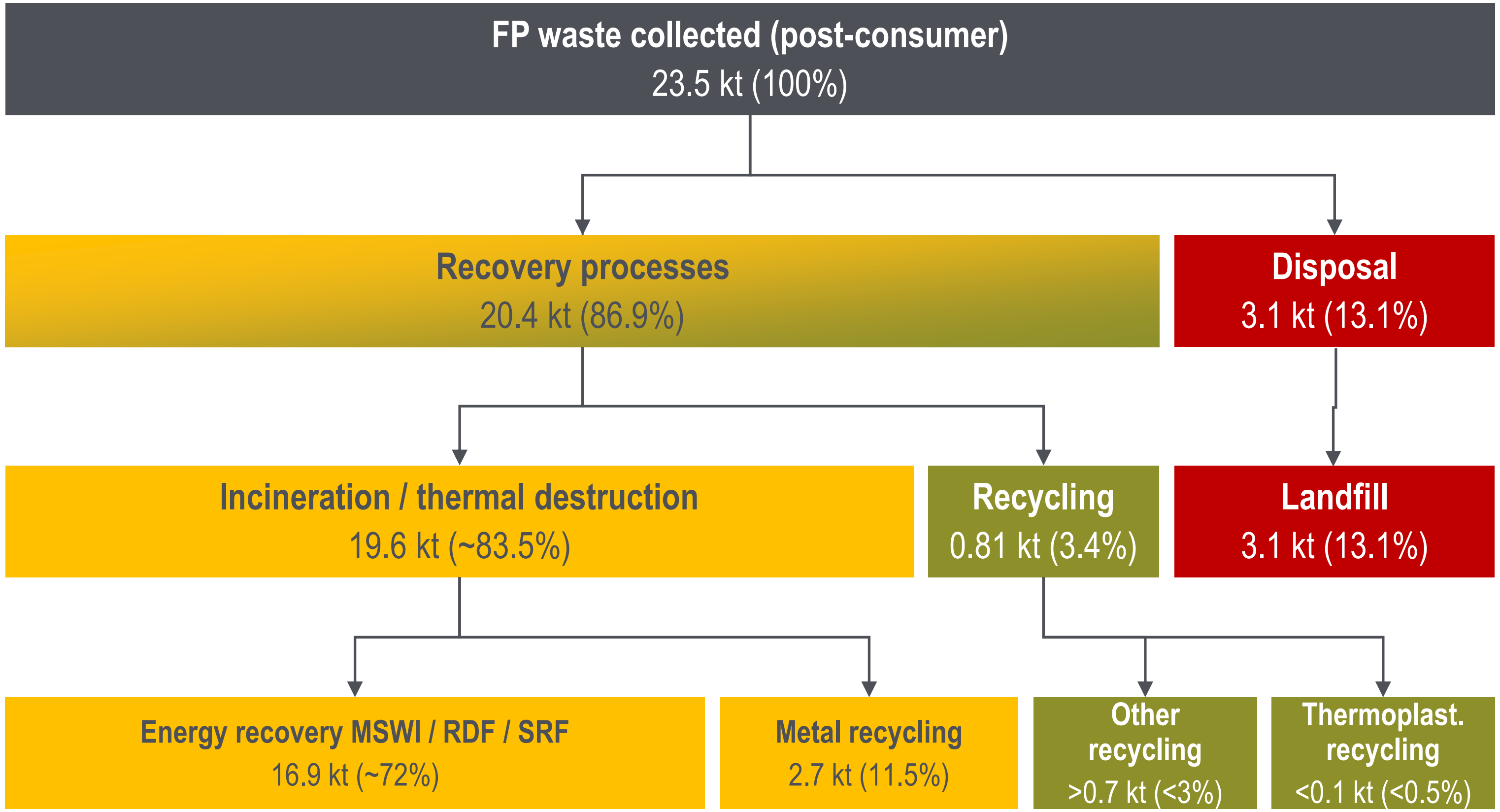
Industry segment	Collected FP waste in kt	Energy recovery in kt	*Share in %*	Landfill in kt	*Share in %*	Metal recycling in kt	*Share in %*	FP recycling in kt	*Share in %*
Automotive	3.5	2.50	*71.4*	0.80	*22.9*	0.20	*5.7*	-	-
Aerospace	0.3	0.24	*80.0*	0.04	*13.3*	0.01	*3.3*	0.01	*3.3*
Electronics & semiconductors	2.7	2.15	*79.6*	0.25	*9.3*	0.15	*5.6*	0.15	*5.6*
Chemicals (CPI)	9.4	7.10	*75.5*	1.05	*11.2*	0.90	*9.6*	0.35	*3.7*
Medical & pharma	2.3	2.00	*87.0*	0.15	*6.5*	0.05	*2.2*	0.10	*4.3*
Other	5.3	2.90	*54.7*	0.80	*15.1*	1.40	*26.4*	0.20	*3.8*
Total	**23.5**	**16.89**	***71.9***	**3.09**	***13***	**2.71**	***12***	**0.81**	***3.4***

(Co-)treatment of FP waste and associated waste streams

FP relevant waste stream	Collected FP waste in kt	Energy recovery in kt	*Share in %*	Landfill in kt	*Share in %*	Metal recycling in kt	*Share in %*	FP recycling in kt	*Share in %*
Residential household waste and municipal waste generated by commercial activities	2.2	1.35	*61.4*	0.85	*38.6*	-	-	-	-
Electronic waste collection (WEEE)	2.3	1.7	*73.9*	0.4	*17.4*	0.15	*6.5*	0.05	*2.2*
ELV incl. auto-shredder residue (ASR)	3.0	2.1	*70.0*	0.7	*23.3*	0.2	*6.7*	-	-
Commercial & industrial (various streams; usually commingled)	15.1	11.04	*73.1*	0.99	*6.6*	2.31	*15.3*	0.76	*5.0*
Total	**23.5**	**16.89**	*71.9*	**3.09**	*13.1*	**2.71**	*11.5*	**0.81**	*3.4*
Other waste streams not further analysed / relevant	0.9	0.7	*77.8*	0.15	*16.7*	0.05	*5.6*	-	-

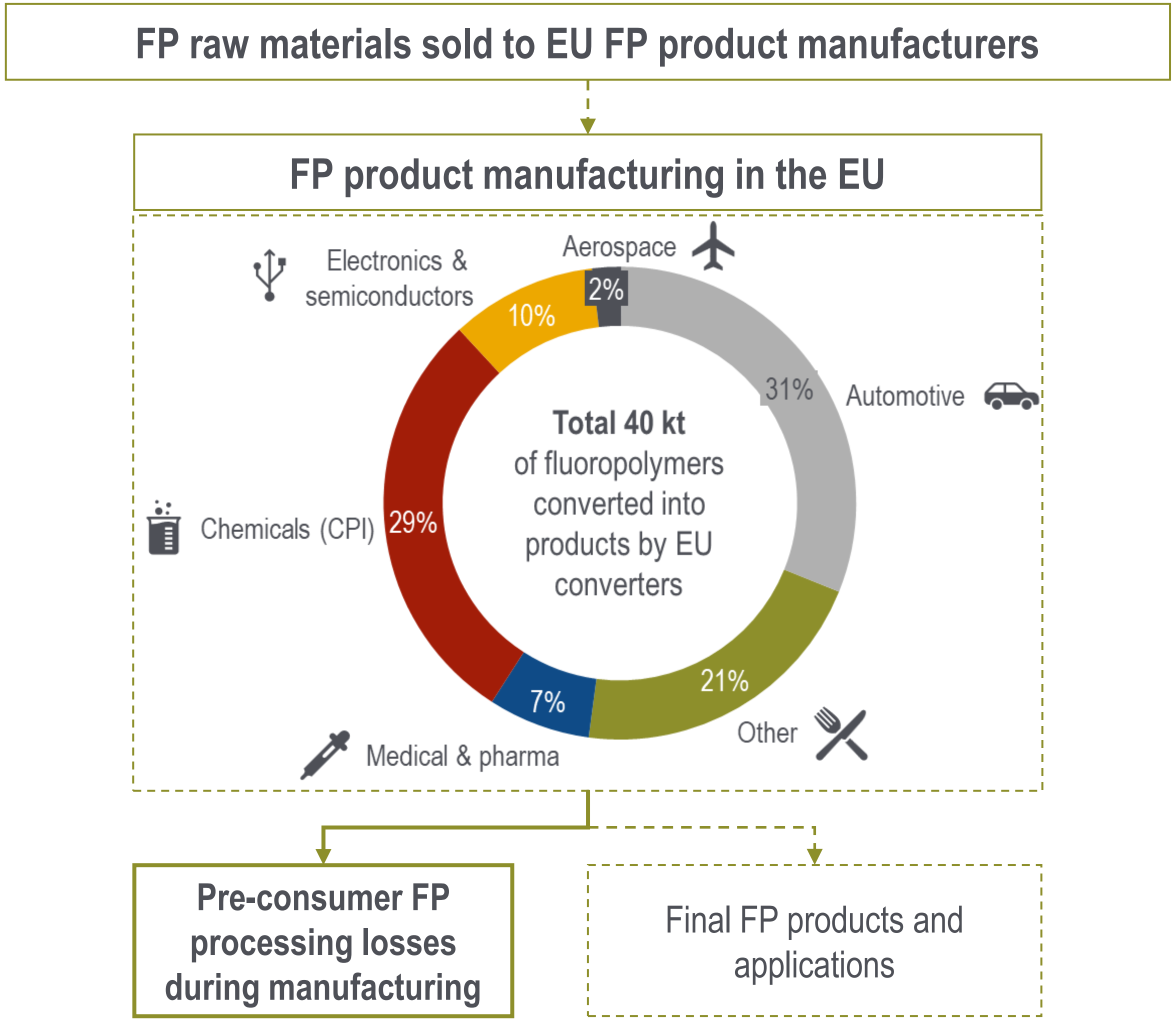
FP waste treatment routes post-consumer FP waste and treatment in the EU in 2020

(Co-)treatment route of post-consumer FP waste in the EU in 2020



- Most FP are (co-)incinerated in MSWI plants or dedicated hazardous waste incineration plants which are for example treating different wastes from chemical waste producers.
- The total penetration of FP waste by mass is in mixed or commingled waste streams typically very low (<0.01%).
- FP waste from commercial and industrial waste producers with is either pre-sorted or results directly from dismantling operations is also mainly incinerated for energy recovery.
- Some fractions of pre-sorted PF waste are send to recycling, either to domestic recyclers or exported for recycling in intra- and extra-EU countries.
- Other recycling includes for example re-grinding and sintering as well as chemical recycling of FP materials.

Pre-consumer processing losses during the manufacturing of FP products and applications



- The processing of FP materials such as the machining of PTFE rods and cubes for the manufacturing of various milled and drilled parts results pre-consumer FP processing losses.
- Due to high costs of FP raw materials, the resulting FP processing losses like shavings, off-cuts or samples are of high value for other companies.
- In total, EU FP product manufactures have process losses of around 20% which means that roughly 8 kt of FP process losses were generated in the EU in 2020.
- Around 20 - 25% of the FP product manufacturers stated to have own internal re-processing steps for their process losses. 30 - 35% stated to send their pre-consumer FP waste to external material re-processing companies and 15% exported their pre-consumer wastes to other companies inside the EU. 5 - 10% stated that their FP processing losses are exported outside the EU for re-processing, e.g., to Asian countries. 5% confirmed that they do not know what happens to their process losses. These companies usually (full-service) contracts with waste management companies. 15% of all FP process losses are not recycled and predominantly (co-)incinerated in MSWI plants or dedicated hazardous waste incineration plants.

Agenda

Case study ELV – 1

Produced new vehicles and collected ELVs with the associated FP volumes

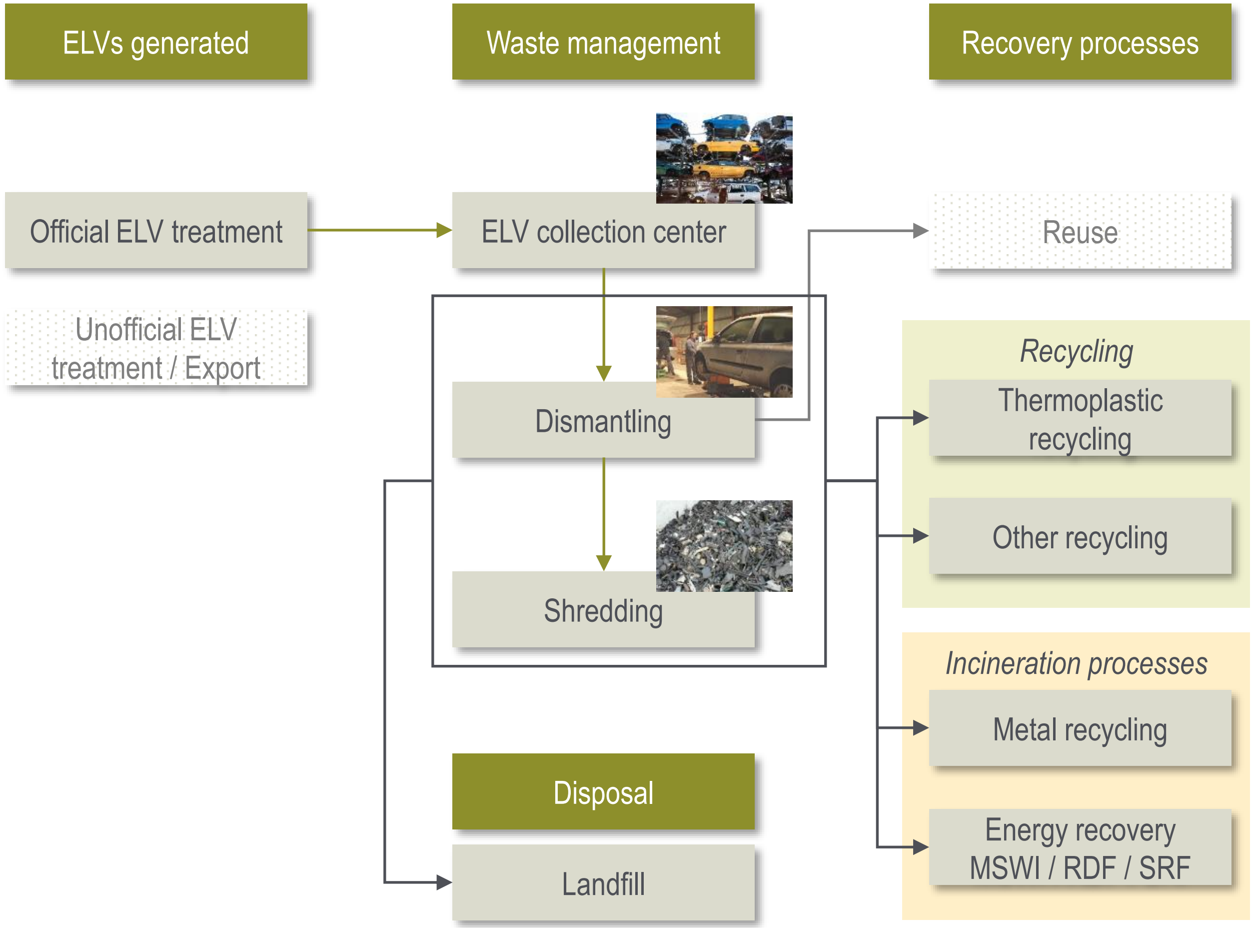
- According to the European Mobility Atlas 2021 by Heinrich Böll Foundation around 12 million cars leave European roads due to total loss after an accident, economic write-off, non-compliance with new safety or emissions standards or a change in design preferences. According the report only around half of them are handled in authorised recycling facilities.
- Using latest Eurostat data for 2019, around 6.9 million ELVs were statistically covered for EU27 + 1.6 million from the UK.
- For 2020, it was assumed that around 8.6 - 8.7 million ELVs were officially collected in the EU27+3 countries which means that there are still statistical gaps between the total number of ELV arisings and the number of ELVs officially collected.
- The FP share in ELVs (usually around 12 years old) is significantly lower compared to modern cars. It was assumed that the average FP content ranged between 0.35 - 0.4 kg per ELV which accounted for around 3 - 3.5 kt of FP materials collected in total in the EU27+3 countries.
- Additional 0.3 kt of FP materials were collected as part of end-of life vehicles >3.5 tonnes, trucks and busses, motorcycles or construction and agricultural (constr. & agricult.) vehicles.
- Most of the collected ELVs undergo a dismantling process where valuable parts (e.g., front and rear lights) or applications with safety issues such as airbags and liquids are removed before the further treatment process.

Fluoropolymers by average weight per new vehicle				
	Cars & LCV	Trucks & buses	Motorcycles	Constr. & Agricult.
Weight	0.7 kg	1.2 kg	0.1 kg	1 kg
EU27+3 production volume for new vehicles 2020				
Number	13.7 million	0.30 million	0.95 million	0.3 million
EU27+3 associated FP volume used in new vehicles 2020 [estimated]				
Total weight	9.6 kt	0.36 kt	0.10 kt	0.30 kt

Fluoropolymers by average weight per ELV				
	Cars & LCV	Trucks & buses	Motorcycles	Constr. & Agricult.
Weight	0.37 kg	0.8 kg	0.1 kg	0.7 kg
EU27+3 total number of collected ELVs 2020				
Number	8.65 million [est.	0.16 million	0.8 million	0.12 million
EU27+3 associated FP waste collected in ELVs 2020 [estimated]				
Total weight	3.2 kt	0.128 kt	0.08 kt	0.08 kt

Case study ELV – 2

Typical ELV processing route



- After ELV collection by registered ELV collection centres, ELVs are dismantled and valuable reusable parts or critical applications such as airbags and liquids, are removed.
- The stripped (and compacted) ELV wrack is then shredded. Shredding facilities often shred ELV wracks together with large appliances. After shredding post-processing and separation processes focus on the recovery of metal fractions.
- EOL FP parts are usually co-treated with metal fractions (metal recycling and thermal destruction of FP materials) or incinerated in MSWI respectively RDF / SRF incineration plants as part of a shredder-light fraction (SLF).
- The post-processing of the SLF can differ. Most shredder facilities have additional recovery steps for the recovery of metals. But only a few plants in Europe focus on the recovery of plastic fractions such as PP or other plastics. Small shares (<0.1%) of FP might end up in plastic fractions sorted for recycling, but the major share (almost 80%) is going into incineration processes and around 20% end up in landfills.
- Lambda sensors are either dismantled separately (recycling of metal- or ceramic-based catalytic converters with focus on the recovery of platin, palladium and rhodium) or shredded together with part of the exhaust system. The attached wire, incl. the FP insulation of Lambda sensors, is often cut off and collected separately for cable recycling. The FP insulation is removed and mainly incinerated with energy recovery.

Case study ELV – 3

ELV treatment in Germany, France, Italy and UK

End-of-life vehicles collected and treated in selected European countries

Sources: Eurostat data 2019, individual ELV country reports by environmental agencies or ELV systems 2019 and 2020, Circular Economy of Plastics 2020 in EU27+3 (Conversio), own model calculations	Germany	France	Italy	UK
Number of ELVs collected	0.46 million (export surplus of used cars)	1.6 million	1.1 million	1.6 million (est.)
Total recycling & reuse rate	86.9%	87.1%	84.2%	85% (est.)
Total plastics quantity	67 kt	160 kt	139 kt	273 kt
Recycling rate of plastics	25%	41% (based on figures by Ademe)	10%	15%
Incineration rate of plastics	69%	27%	10%	55%
Landfill / disposal rate of plastics	6%	32%	80%	30%
Thereof FP quantity	0.16 kt	0.56 kt	0.39 kt	0.56 kt
Incineration / thermal destruction rate of FP	>95%	>80%	>50%	>60%
Landfill / disposal rate of FP	<5%	<20%	<50%	<40%

Case study Aerospace

- According the Centre for Aviation (CAPA) statistics, around 7,500 commercial aircrafts are in service by Western and Central + Eastern European airlines.
- In Europe, each year about 250 - 300 commercial aircrafts reach their end of service life. Thereof approx. 180 - 220 aircrafts remain in Europe for further dismantling and recycling operations. Commercial aircrafts are also exported to extra-EU countries for reuse. In addition, more than 300 aircrafts are stored in large open spaces either for reactivation or for spare parts supply.
- The Aircraft Fleet Recycling Association (AFRA) estimated that around 15,000 aircrafts will retire in the next two decades worldwide incl. around 2,000 - 3,000 aircrafts in Europe.
- The French company Tarmac Aerosave has three sites where up to 280 aircrafts can be stored for longer periods. Over the past years, the company has recycled over 300 aircrafts (75% of all Airbus A340 aircrafts worldwide). Additional aircraft dismantlers and recyclers in Europe are, for instance, ecocube (UK) with focus on aircraft EOL treatment (overall market share >40% in Europe and ~20% worldwide), AELS with >75 aircrafts recycled since business start (Netherlands), Air Salvage International (UK), Roth International (Germany / Czechia), Cronimet (Germany) and JAS Jet Aircraft Services (Netherlands).
- The focus of aircraft dismantlers and recyclers is to extract valuable and reusable parts as well as recovery of metal fractions such as skeleton and cladding. Non-recyclable materials are mainly incinerated for energy recovery operations. Only a small share of plastics, incl. a small share FP materials, is landfilled, e.g., in the UK or in France.

Fluoropolymers by weight per average new aircraft	
	Average
Weight	120 kg
EU27+3 production volume for new aircrafts 2020	
Number	566 (Airbus figures, 611 in 2021)
EU27+3 associated FP volume used in new aircrafts 2020 [est.]	
Total weight	68 tonnes (excl. 10 - 15 kt sold in Boeing aircr.)

Fluoropolymers by average weight per end of life aircraft	
	Average
Weight	100 kg
EU27+3 total number of EOL aircrafts 2020	
Number	200
EU27+3 associated FP waste collected in EOL aircrafts 2020 [est.]	
Total weight	20 tonnes

Case study WEEE – 1

WEEE management and protentional FP circularity approaches for end-of-life electronic & semiconductor production and processing equipment

- In the most European countries WEEE management systems have been successfully established for the collection, categorizing, dismantling and treatment of WEEE.
- Despite the success of these dedicated WEEE management systems which provide high market coverage of the generated electronic waste in many countries, there is still a lot of mismanagement of electronic waste even in wealthy industrial countries. Illegal exports of electronic waste (often categorized as 'used electronics') to countries with improper recycling environments is one of the issues that should be addressed by EU legislators in the coming years.
- The domestic WEEE management in countries such as Germany, France, Italy or the UK, is mostly safe if done properly. Most WEEE arising is covered by dedicated WEEE streams. Additional volumes are collected, for example, through residential waste streams and a small share through mixed commercial and industrial waste streams. The major share of end-of-life electronics which are not routed for recycling is going into waste incineration.
- There are some WEEE recovery operations established for obtaining recyclable plastic fractions, incl. ABS, PE-HD, or PS. The recovery of FP materials is more or less limited to the recycling of production and processing equipment, e.g., FP piping for ultra-pure water / solvent supply.
- The WEEE collection does not cover information about associated production and processing equipment, e.g., FP materials used semiconductor or chip manufacturing plants. These material streams are usually collected as part of commercial and industrial waste streams either on behalf of specialized service companies or larger waste management companies.
- A circularity approach for end-of-life FP materials should be directly addressed with electronic & semiconductor manufacturers respectively users of FP production and processing equipment. Closed-loop recycling systems will only be functional, if chip manufacturers such as Semikron (Germany), Diodes Incorporated (UK), GlobalFoundries (Germany), Nexperia (Germany), STMicroelectronics (France and Italy), Analog Devices (Ireland), TDK - Micronas (Germany), X-FAB (Germany), etc., will be involved. The overall FP volumes that can be recovered from end-of-life production and processing equipment will probably be relatively small, but it's one step closer towards the circularity of FP materials.




Case study WEEE – 2

WEEE treatment in Germany, France, Italy and UK

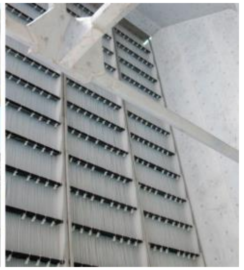
End-of-life vehicles collected and treated in selected European countries

Sources: Eurostat data 2019, individual WEEE country reports by environmental agencies and WEEE systems, Circular Economy of Plastics 2020 in EU27+3 (Conversio), own model calculations

WEEE systems	None, but Stiftung EAR (central monitoring of WEEE)	Major two players are Ecosystem and Ecologic	13 non-profit WEEE collection systems	Around 25 - 30 WEEE collection systems
Collection rate of WEEE systems	n.a. (60 - 70% collection rate)	60 - 70%	40 - 50%	40 - 60%
Total WEEE collected	1,030 kt	855 kt	365 kt	680 kt
Thereof plastics	240 kt	160 kt	85 kt	135 kt
Recycling rate of plastics	28%	59% (based on figures by Ademe)	23%	44%
Incineration rate of plastics	72%	28%	46%	47%
Landfill / disposal rate of plastics	<1%	13%	31%	9%
Thereof FP quantity	0.47 kt	0.39 kt	0.17 kt	0.31 kt
Incineration / thermal destruction rate of FP	>99%	>85%	>70%	>90%
Landfill / disposal rate of FP	<1%	<15%	<30%	<10%

Case study industrial processes – Chemical, Energy, Food & beverage, Pharma, Semiconductor 1

- The Chemical industry is using FP materials for many different applications, mainly for corrosive substances or environment with higher temperature levels.
- After a certain period of time these FP applications need to be dismantled and replaced to keep downtimes of production processes and risk of malfunctions as low as possible.
- Average lifetimes of liners and other affiliated FP products used for chemical production processes range between 10 and 20 years. Lifetimes can be as low as 1 year, e.g., for high-purity applications and very aggressive substances and demanding production environments and can go up to 50 years for (thicker) tubes and pipes used for less aggressive substances in less demanding production environments.
- For the replacement of FP applications used in production and processing equipment different practices are common. Either internal maintenance service departments (often contracted third-party companies on site) are responsible or external (and specialized) service companies provide services on request. A combination of both practices on one site is also possible.
- After dismantling end-of-life pipes, valves, pumps, tanks, etc., (incl. FP liners) or PF tubes, pipes, hoses, seals, filters, etc., are collected as waste and mainly separated on site for further waste treatment.
- Steel pipes incl. FP liners are usually collected for metal recycling. Some companies extract the FP content for further processing or to simply increase the average recyclable metal content which is then sold to metal recycling companies.
- Most of the FP materials from chemical industry applications are usually collected (separately) by private waste management companies for waste incineration, either in MSWI or hazardous waste incineration plants. Smaller FP quantities are also collected in commingled (mixed) waste fractions which usually are also send to waste incineration processes.
- Within the power industry segment, larger volumes of FP are, for example, collected from flue gas lining and piping with an average lifetime/ replacement frequency of about 10 to 15 years, for instance, in coal-fired power plants as well as in other processes where industrial flue gas coolers are used. Hereby also larger volumes of pre-sorted and 'clean' FP material streams can be obtained, e.g., for chemical recycling processes.

Case study industrial processes – Chemical, Energy, Food & beverage, Pharma, Semiconductor 2

- Europe is one of the largest chemical production location in the world. Companies such as BASF, DuPont, Ineos, LyodellBasell, Air Liquide, Linde, Evonik, Covestro, TotalEnergies, Bayer, etc., are only a couple of exemplary users of FP production and processing equipment as well as possible contributors to a potential FP circularity model.
- In addition, a cooperation between waste service companies and larger chemical parks with many different companies on site could also contribute to substantial quantities of recyclable FP materials.
- Some users of FP production and processing equipment stated concerns related to product safety issues that might occur for some of the FP material equipment that has previously been used for hazardous substances such as aggressive chemical media, that might lead to health and safety issues. Accordingly, companies often require third party waste management companies or service providers to treat their end-of-life materials as safely as possible (i.e., hazardous waste incineration).
- Another issue was raised by Pharmaceutical companies. Due to patent and legal requirements these companies could restrict the recycling opportunities of end-of-life FP production and processing equipment.
- Concerns were raised, e.g., for materials that have previously been used to produce drugs or specific production aids.
- Besides all concerns, end-of-life industrial production and processing equipment offers the best opportunity to collect significant volumes of recyclable FP materials. The post-sorting of commingled waste streams to obtain FP materials for recycling is not an option as the overall penetration of FP is too small (often <0.01% by total mass). The industry should focus on pre-sorted material streams such extracted FP pipe liners or FP tubing and piping to create a robust circularity model for end-of-life FP waste.
- Circular economy approaches for FP materials should be targeted for Chemical, Energy, Pharma and Semiconductor production and processing equipment as these industry segments account for significant volumes of FP waste collected.

EU27+3 Fluoropolymers utilized for different production and processing applications 2020						
	Chemical	Energy	Food & beverage	Pharma	Semiconductor	**Total**
FP quantity	9.5 kt	2.0 kt	1.2 kt	1.6 kt	1.7 kt	**16.0 kt**

EU 27+3 Fluoropolymer waste collected 2020 [estimated]						
FP quantity	7.6 kt	1.8 kt	0.9 kt	1.2 kt	1.5 kt	**13.0 kt**

Case study industrial processes – Chemical, Energy, Food & beverage, Pharma, Semiconductor 3

Commercial & industrial waste treatment in Germany, France, Italy and UK

Commercial & industrial (mixed) waste collected and treated in selected European countries

Sources: Individual country reports by environmental agencies, Circular Economy of Plastics 2020 in EU27+3 (Conversio), own model calculations				
Waste separation	Extended source / on site separation into different fractions	Limited source / on site separation into different fractions	Limited (Central/South) to extended (North) source / on site separation into different fractions	Limited source / on site separation into different fractions
Total C&I mixed waste collected	54,000 kt	55,000 kt	48,000 kt	21,000 kt (different collection scope)
Thereof plastics	1,010 kt	580 kt	560 kt	420 kt (different collection scope)
Recycling rate of plastics	26%	7%	10%	8%
Incineration rate of plastics	73%	46%	43%	55%
Landfill / disposal rate of plastics	1%	47%	47%	37%
Thereof FP quantity	2.7 kt	2.0 kt	1.3 kt	1.8 kt
Incineration / thermal destruction rate of FP	>99%	>80%	>80%	>85%
Landfill / disposal rate of FP	<1%	<20%	<20%	<15%

Case study cookware

- Metal-based consumer and professional cooking equipment such as pans, pots and trays, is usually made of different metals incl. steel, aluminium and copper and a coating.
- Coatings of cookware usually focus on reducing the stickiness of bakery and other food products as well as minimizing the risk of burning in. These characteristics are, for example, beneficial for industrial sized food processing equipment or regular pans and pots which can be found in households.
- The overall FP content which is used for a regular frying pans (i.e., often referred to as Teflon coating) ranges between 6 - 12 g (on average 8 g). Frying pans weigh between 0.5 and 3 kt (on average 0.8 - 1 kg), accordingly the average FP mass per frying pan by weight is just below the 1% mark. According to different Eurostat product datasets, it can be estimated that around 250 Mio. t of coated (consumer) pans, pots and trays were put on the market in the EU in 2020.
- The total FP weight used for coated consumer and professional cookware was estimated to approx. 2 - 2.5 kt in 2020 of which the largest share accounted for consumer frying pans.
- After use, coated end-of-life frying pans are collected in different waste streams. Some countries have restrictions for the collection of coated pans due to safety concerns related to waste treatment and recycling.
- In addition, recyclable pans or often disposed of in mixed residential waste streams and, therefore, lost for any recycling approach (waste incineration or landfill). Mixed recyclables collection such as the 'Wertstofftonne', where different recyclable waste materials made from plastic or metal are collected, offer the opportunity to reach significantly higher recycling shares from end-of-life cookware via automated sorting facilities compared to recyclables bring-in stations or dedicated metal scrap collectors. Manufacturer take-back systems for old pans when buying new ones, are also an opportunity to collect 'clean' fractions of end-of-life cookware for metal recycling.
- The recovery of plastic fractions for recycling (e.g., handles) is not targeted by most recycling companies. These materials are incinerated, landfilled or thermally destructed (metal recycling furnace). There are also no technologies available to recycle the FP content from coatings.

EU27+3 Fluoropolymers in new cookware 2020	
FP quantity	**2.3 kt**

EU27+3 Fluoropolymer waste in EOL cookware 2020 [estimated]	
FP quantity	**2.1 kt**

Agenda

Status quo – recycling of FP materials

- The recycling of FP materials today is often limited to 'clean' pre-consumer materials from FP manufacturers. Only small volumes of post-consumer FP materials are recovered for recycling.
- 20 - 25% of all FP product manufacturers stated to have own internal re-processing steps for their own process losses. 30 - 35% pass on their FP pre-consumer waste to external material re-processing companies (recyclers). 15% export their pre-consumer wastes to other companies inside the EU (export for recycling intra-EU). 5 - 10% export their FP processing losses to countries outside the EU, e.g., to Asian countries for further processing (export for recycling extra-EU).
- Recycling of post-consumer FP waste from commingled (mixed) waste streams either from households and comparable sources or from commercial and industrial end-users is not existent and will not be a promising option for circularity of FP in the coming years. The overall share of FP is too low to establish any sorting and recycling approach.
- The recycling of post-consumer FP waste is more or less limited to the recovery and separation of 'clean' fractions, e.g., from commercial and industrial production and processing equipment (around 13 kt in total). The accessible quantity of post-consumer FP waste suitable for recycling is significantly smaller. Only if all stakeholders along the FP value chain work more closely together, progress can be made on the circularity of FPs.
- A common recycling process is to grind PTFE waste into a fine powder and blend this powder with pure PTFE to be used either in compression moulding or ram extrusion processes. Before grinding, PTFE waste is usually heated to above its melting point to remove any organic contaminants. Once ground, it is treated with acid to dissolve inorganics after which it is washed and re-heated to vaporise any volatiles (i.e., recycling could be described as a sintering process).

Extract of existing FP recyclers in Europe
(excl. chemical recycling and trading / export of FP waste for recycling)

- Krall Kunststoff-Recycling with focus on technical plastics waste such as PC and PMMA but also PA, PEEK, PPSU, PSU, PVDF, PTFE, PEI
- Heroflon (Daikin) with focus on PTFE waste
- MCAM Symalit (Mitsubishi Chemical Holdings Corporation) with focus on PVDF, ECTFE, ETFE, PFA, FEP, PEEK
- Ambofluor with focus on PVDF, ETFE, ECTFE, FEP, MFA, PFA, PTFE
- Prodotti (Fluormetal) with focus on PTFE
- Shamrock Technologies with focus on PTFE
- Mikro-Technik with focus on PTFE
- United Polymer Mixers (UPM Kunststoffen) with focus on PTFE

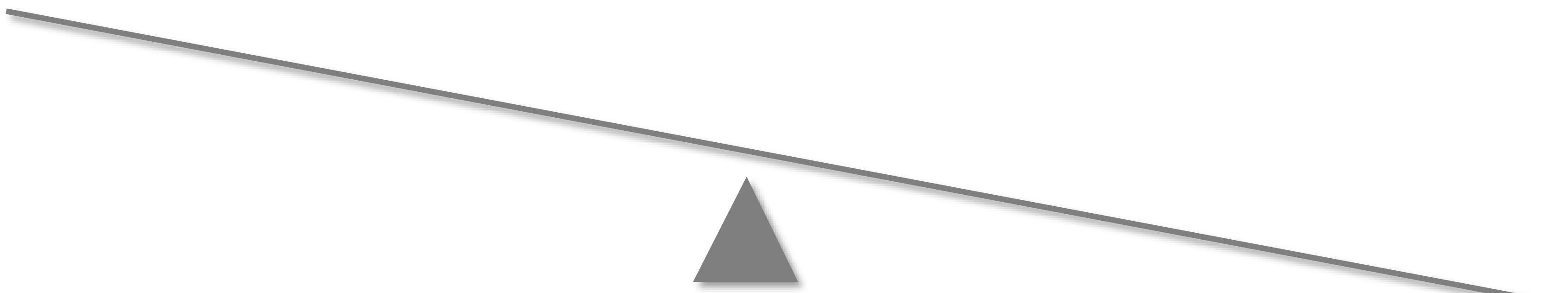
Critical success factors for the circularity of FP – drivers & barriers

Drivers

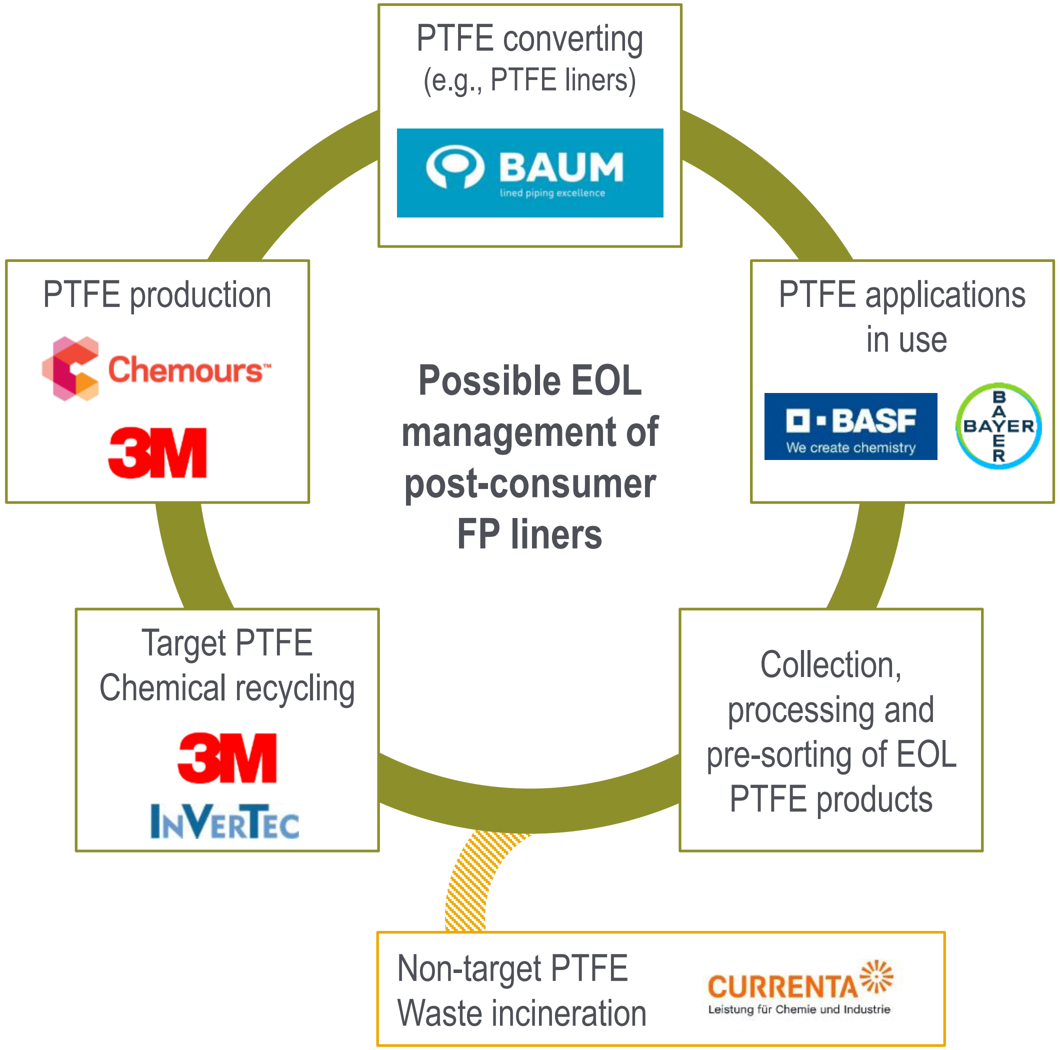
- High cost of raw materials / limitation of accessible raw materials
- Existing chemical recycling plant with a capacity of 500 t p.a.
- Cooperation only between few stakeholders necessary
- Relatively 'clean' material streams if selected properly

Barriers

- Various applications with overall small FP volumes
- Limitation to selected and pre-sorted EOL material streams
- Logistical efforts to collect sufficient volumes for recycling
- Objections from the industry related to 'product safety issues'



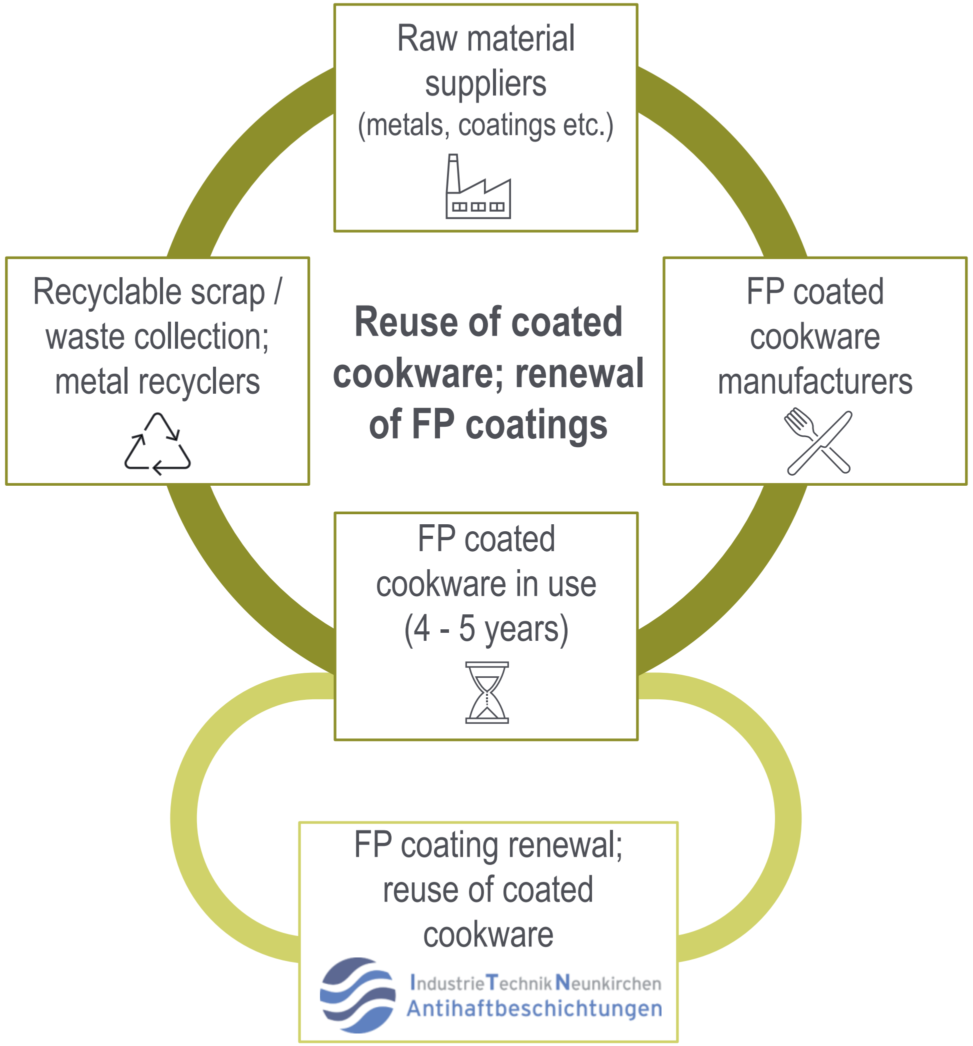
In-depth circular economy approach for FP pipe liners



- Today, the recovery of post-consumer EOL fluoropolymer waste often relies on (co-)incineration in waste incineration plants.
- After production and converting of PFTE into products and applications, commercial end-users such as large petrochemical companies (e.g., BASF or Bayer), usually send their EOL products to MSWI plants, mainly via contracted service or waste management companies.
- The existing pilot plant by 3M (former Dyneon) in Gendorf/Germany is capable to recycle 500 t of post-consumer PTFE, PFA or ETFE materials per year by cracking fluoropolymers into monomers (chemical recycling). These monomers can be used to produce new fluoropolymer raw materials. Besides 3M, InVerTec is also able to provide turn-key chemical recycling plants for fluoropolymer end-of-life applications.
- A circularity target could be the set-up of a closed material circle in the coming years. Collected EOL FP products from commercial end-users could be sent to ‘up-cycling plants’ and the extracted monomers could be distributed back to PTFE raw material producers.
- In order to create more economic viable chemical recycling opportunities. A plant should cover a processing capacity of about 2 kt/p.a.. If 5 of these plants are built in the coming years, about 10 kt of post-consumer FP material could be recycled in the EU, which would represent about 20 - 30% of the annual FP processing capacity.
- Together with other companies, the manufacturer BAUM is currently working on a closed-loop solution for the recovery of PTFE and other PF EOL products.

In-depth circular economy approach for FP coated cookware

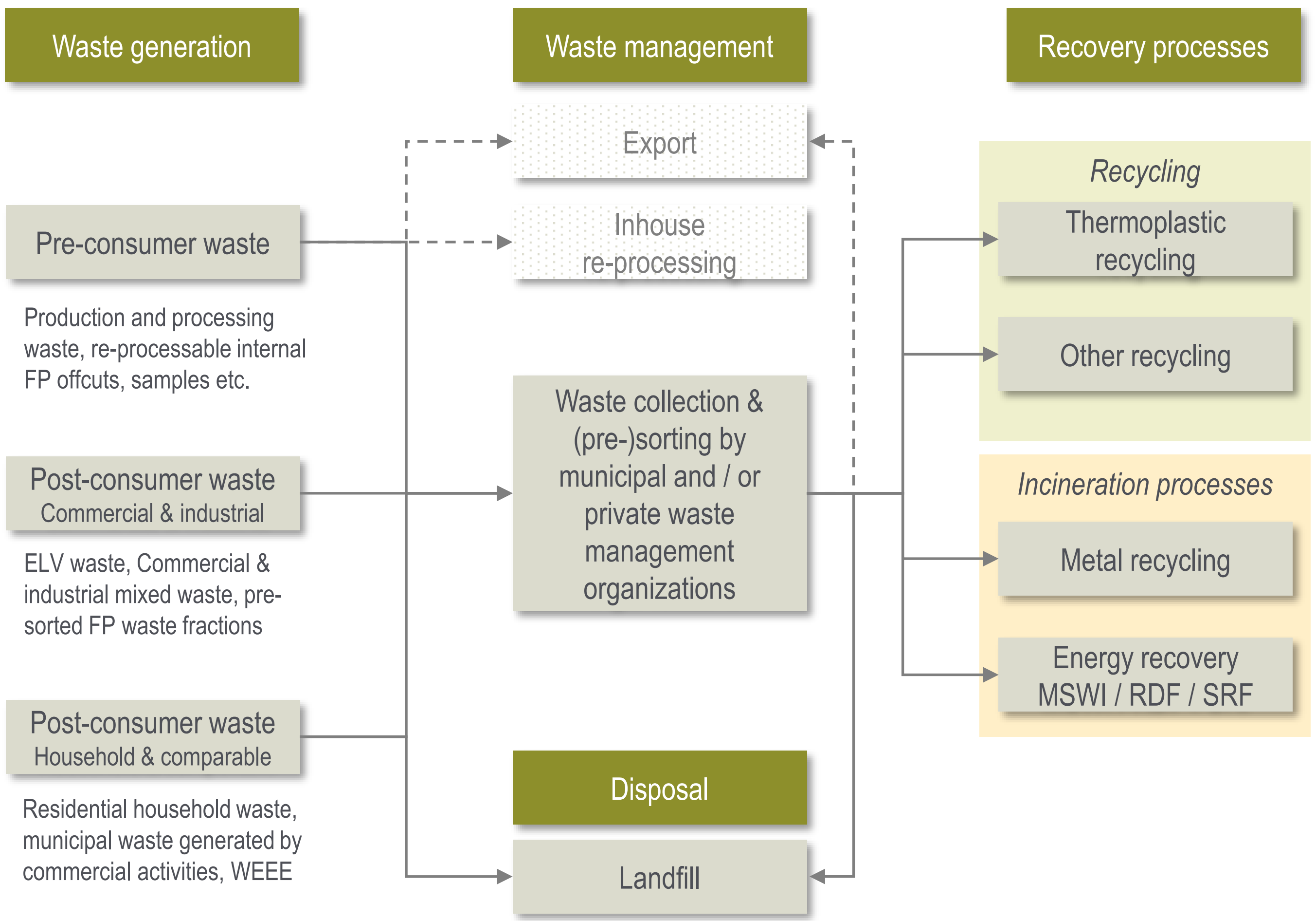
- The average use phase (i.e., lifetime) of coated cookware is highly dependent on the frequency of use or disregard of the maximum approved temperature respectively scratching of the coating, e.g. with metal cookware. Small scratches and slight colour changes of FP based coatings are often only aesthetical disadvantages and do not impact the mechanical/ chemical characteristics of the coating. Coated cookware should be replaced, if proper functionality (i.e., reduced anti-stick characteristics) is not given anymore.
- Another option is applying a new FP based coating. Some manufacturers of cookware and coatings (e.g., BAF, Olav and ITN) already offer a solution where the used pans and pots can be sent in for renewal of the non-stick coating. ITN offers its services for all metals and all cookware manufacturers. The company removes the old coating (sandblasting) under controlled conditions, incl. dust and particle extraction measures, and applies new PTFE based coatings.
- The renewal of anti-stick coatings is one way to extend the longevity of coated cookware. The service life of FP-based coatings is estimated by manufacturers to around 4 to 5 years on average. Applying a new FP based coating would accordingly double the average lifetime and offer another opportunity to reuse 'old' cookware with the characteristics of a new product.



Agenda

Typical treatment route of mixed residential and commercial & industrial waste streams

FP waste collection and treatment route



- FP pre-consumer waste respectively reusable materials are often sent to recyclers or are internally re-processed again. Intra and extra-EU export of pre-consumer FP waste is also common.
- Post-consumer waste incl. FP waste from commercial & industrial end-users is primarily managed by private waste management companies. Post-consumer FP waste from private households is mainly managed by municipal waste management companies and (co-)contracted private waste management companies.
- The largest share of FP waste in commingled waste streams such as mixed residential household waste, commercial and industrial mixed waste or shredder light-fractions of ELV and large appliances shredder facilities is not post-sorted for recycling. Accordingly, almost all FP waste fractions are (co-)incinerated in MSWI or hazardous waste incineration plants. A smaller share of FP waste is incinerated in commingled fractions in dedicated RDF or SRF plants, e.g., cement kilns.
- Only pre-sorted and ‘cleaner’ FP waste fractions from end-of-life applications such as pipe liners or tubes and pipes are suitable waste streams for recycling. Post-sorting of FP materials from mixed waste streams is not feasible, neither technical nor economical.