

Soft Foam Circles

Management summary – Pre-Read



May 2, 2023






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SuP approach and sources

Pre-read

Main sources for this study are expert interviews with key players along the value chain, a consumer survey and market reports from CSIL, Europur and macro-economic sources.

Sources and data assessment

-  **90 interviews** with key players in (EoL) PU industry and technology experts
-  Online **consumer survey** in 6 major EU countries with **1,800 participants**
-  **CSIL data**, external market reports (e.g. **EUROPUR**), SuP **internal databases**
-  **Cross checks** financial reports (e.g. of dismantlers)
-  **Regular meetings and workshops** with the client for double checks (and usage of internal expertise)

Selected interviewed companies

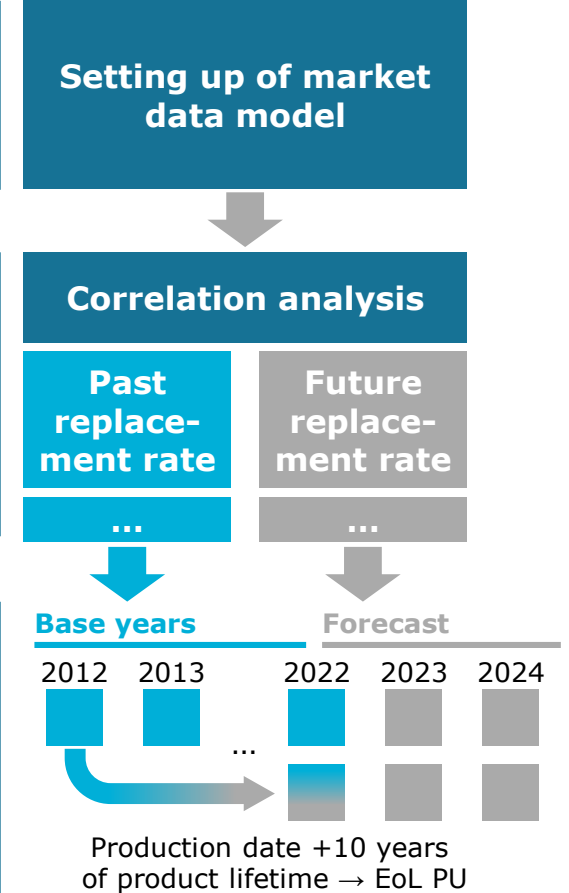


Illustration of market data gathering

Gathering of all relevant data per country, e.g. mattress sales, amount of PU consumed/ share, etc.

- Correlation analysis & indicator definition
- Indicators based on interviews, reports and the consumer survey

- Usage of historical PU demand data to model EoL amount after product lifetime
- Forecast based on macroeconomic & trend indicators



Sources: desk research, interviews, analysis & SuP expertise, EoL: End of life

Reference, background and objectives

Pre-read

Objective of the project is to draw an outlook on the availability of EoL PU and the expected price level.



Reference

- The RfP provided on June 09, 2022 as well as the presentation of proposal on July 25, 2022 and the following e-mail conversations.



Background

- The client is a leading chemical company that produces chemicals for different applications. In addition to virgin products the client is continuously working on new technologies towards a circular economy.
- Chemical mattresses recycling is one of the new technologies for the client.
- The target of this market studies is to get insights in market development and price forecast for recycled polyurethane from end-of-life (EoL) mattresses.



Objectives

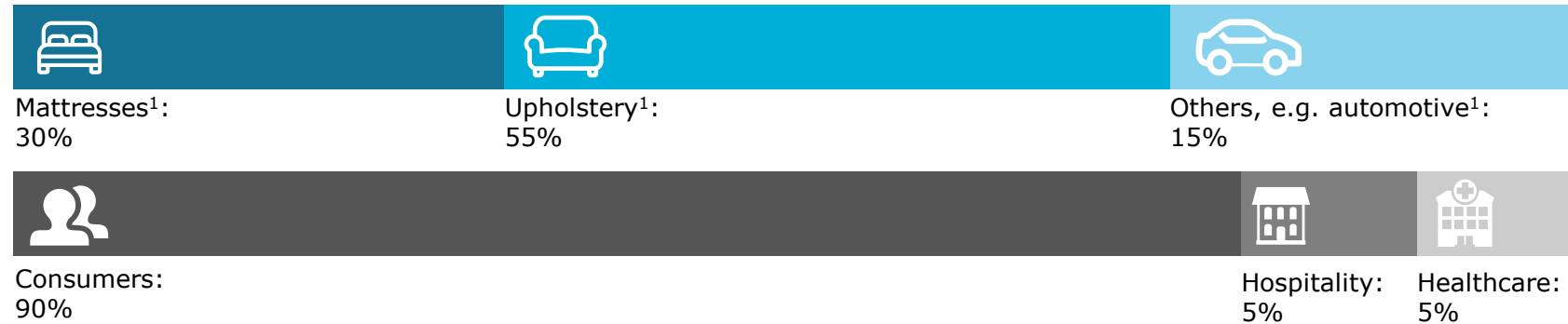
- Understanding the current and expected market size for EoL polyurethane and the respective technologies
- Getting insights into the cost position of the different recycling technologies
- Developing an outlook on potential price levels for EoL in the future
- Drawing a cost curve of the European EoL PU market

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Demand patterns for mattresses & upholstery

Pre-read

The PU foam market is mostly relevant for mattresses and upholstery for consumers with replacement times of above 8 years.



How often do end-consumers dispose their mattress or couch on average?

	Average	France	Germany	Italy	Netherlands	Poland	Sweden
Mattress	8.2	9.0	7.1	9.2	9.7	5.7	8.4
Upholstery	8.9	8.9	9.5	8.5	9.5	7	9.8

1. Market distribution based on SuP model based on Europur and CSIL data

Sources: SuP desk research, Consumer panel with 1,800 participants, n=300 per country

Voice of market

We see an increasing consumer pull in the market for sustainable mattresses.
- Neveon

Majority of customers wait for the legislation but the foam industry needs to anticipate this and be ready.
- Vita Group








Producers and retailers need to start with an awareness process work with our people in the service, make our coworkers point of contact to the consumer.
- IKEA

There is awareness in the market from consumers, but most of them are not the driving force.
- Mattress & upholstery association

Willingness to pay

Pre-read

Willingness of consumers to pay more for sustainable PU solutions increases. Acceptable price premium on mattress level in Europe is around 6%.

Current mattress costs mentioned by consumers		Willingness to pay for a mattress made with recycled materials		Willingness to pay for a mattress made with bio-based materials	
 Wt. average	612 EUR	632 EUR	3%	676 EUR	9%
	717 EUR	746 EUR	4%	776 EUR	8%
	505 EUR	528 EUR	5%	564 EUR	12%
	703 EUR	712 EUR	1%	736 EUR	5%
	717 EUR	710 EUR	-1%	725 EUR	1%
	469 EUR	509 EUR	8%	573 EUR	22%
	667 EUR	633 EUR	-4%	681 EUR	4%

% Weighted average price premium

Consumer awareness:

- Often consumers are not aware of the nature of PU foam, what it is made of and how it is treated after its end of life.
- Term recycled mattress often misunderstood (old mattress being resold & reused).

Strategic implications:

- Average price premium between 3% and 9%.
- Especially in countries with low mattress prices, willingness to pay extra for sustainable products is high.

What recycling really means is often unclear to consumers and thus they are not really willing to pay extra.

- Federal Eco Foam

I would say a price surplus of 5-10% is acceptable for most consumers.

- Independent consultant (ex Covestro)

Sources: Consumer panel with 1,800 participants, n=300 per country

Regulatory environment and actions by market participants

The main push for recycled PU foam is expected from regulatory bodies.
A mandatory recycling content of 25% is expected in 2028, with increasing targets until 2040.

Regulatory



Highest impact:
law to foster circular economy

- The **announcement of new EU regulations** has brought the whole mattress industry into motion.
- **Upcoming laws** (e.g. ESPR, waste shipment directive, etc.) will have the most impact, with regulations for **extended life span of mattresses, reparability and design for recycling.**

Brand owner / retailer



Lack of downstream involvement

- **EPR schemes** often still **limited to extra payment for the official recycling infrastructure**, without producers taking responsibility for the recycling itself, e.g. through participation in collection.
- Retailers with take back schemes often do **not encourage** them and also take EoL mattress to the local collection points.

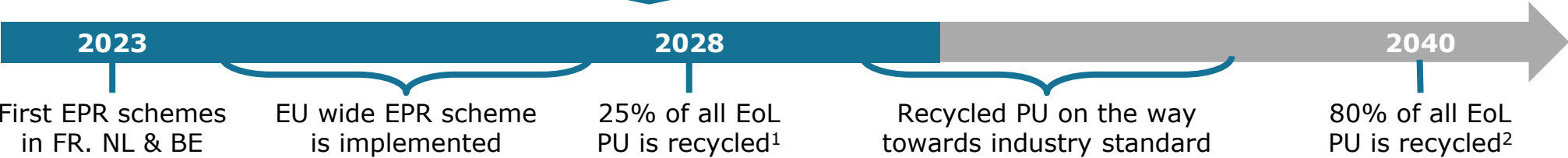
Waste stream



Lack of transparency and communication

- The current waste stream is very **non-transparent, fragmented and there is a lack of communication** between the stakeholders.
- Transport across country borders challenging
- Real recycling of EoL mattresses is still a real challenge due to a **lack of infrastructure** to get EoL mattresses to recycling plants in the **required quality.**

Assumed EoL PU timeline in the EU



1. Key stakeholders mentioned a range of 20 – 30% recycled content in the timeframe of 2028 – 2030
2. Estimated based on EU sustainability goals

Sources: SuP interviews & analysis; ESPR: Ecodesign for Sustainable Products Regulation

Challenges for circularity of PU

Pre-read

The market expects EPR schemes together with increased awareness for circularity of PU to be the main drivers.

"Ikea has been on a journey to **decrease virgin fossil-based materials in its foam mattresses** and develop foam solutions centered **around recycled materials.**"

- IKEA

"**Chemical recycling** will become the main way to **deal with the huge quantities of mattresses.** This is the **only way** to cope with it."

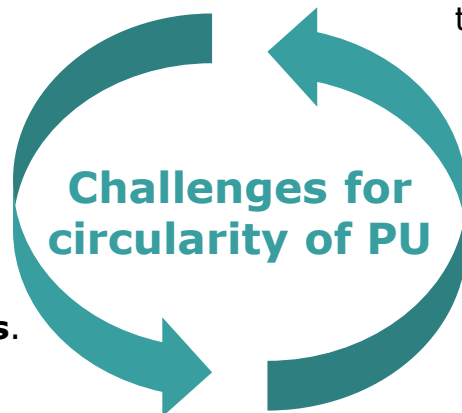
- Europur

"**EPR schemes have to be implemented**, which is currently happening in Europe. I think in the future we will have a **system similar to batteries, where every mattress is charged a certain extra amount to pay for the recycling cost.**"

- Mattress association

"**Without governmental support** and a **regulatory framework** there won't be certainty about where the road is heading."

- Leading Foamer



"**We constantly compete against incineration plants.**

Even though the cost for recycling would be higher we need to stay within the price range of incineration. If an adequate landfill or incineration capacity and infrastructure exists, it is difficult to develop cost effective alternatives or set ambitious targets for recycling. We are as recyclers reliant on a relatively local supply of waste mattresses.

- Recycling company

"**80% of EoL mattress**, at least, are still dealt with by the **local municipalities. 25% of the mattresses** reaching the waste parks are **not suitable for recycling.** They are **too wet or dirty.** Especially, when they are from larger cities curb side."

- Retailer

"**Low incineration prices** and **missing EPR schemes** make it **challenging** to make something happen in PU recycling. (...)
In countries like the **Netherlands** we see an **oversupply of EoL mattresses** that cannot be properly managed."

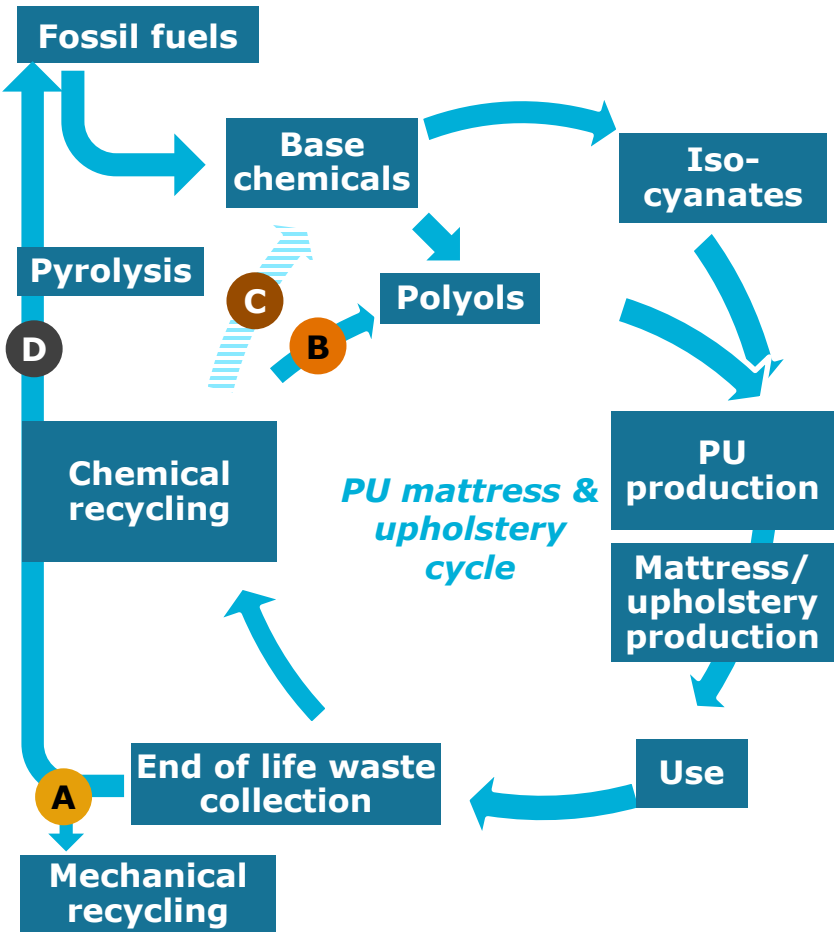
- Dismantler

Sources: desk research, interviews, analysis & SuP expertise, EoL: End of life; EPR: Extended producer responsibility

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Existing solutions for recycling of EoL PU (landscape overview)

Only the “high end” chemical recycling has the ability to fully close the loop in the PU industry recovering both polyols and isocyanates.



Method	Active player	Input material	Output material	Process maturity	Process cost competitiveness	CO ₂ reduction ¹	Closing PU loop
A Mechanical recycling/rebonding	Various leading players in the PU industry	All sorts of EoL PU material that can be glued together	Rebonded EoL PU foam with lower softness	Established process with high & increasing capacity		Product used for non-mattress applications	Down-cycling/
B “Low key” chemical recycling		Sorted EoL PU with a lower sensitivity towards contamination	Polyol with high virgin content & organic residue ²	First small demonstration plants but not yet commercial			Re-polyol only
C “High end” chemical recycling		Sorted EoL PU with a higher sensitivity towards contamination	Both polyols & amines can be recovered ³	Pilot plants only and not yet commercial	-		
D Pyrolysis	Various active in research	Variety of different materials (depending on process)	Recovery of organic building blocks of PU	Early stage with first applied research plants			

Incineration/ “thermal recycling” not included due to limited contribution to circularity and treatment as such by the market and authorities (together with high CO₂ footprint and cost)

1. Compared to next best alternative: incineration of EoL PU

2. High amount of virgin polyol, leading to recycled polyol content in polyol output <20%; organic residue contains various building blocks that cannot be used without further processing

3. Differences in exact output of the amine fraction of both processes which needs to be further processed to be used as raw material for PU again























Sources: desk research, interviews, analysis & SuP expertise, EoL: End of life

Competitive overview – Recycling technology

Pre-read

Within the two groups of chemical recycling Repsol is technologically superior over Dow while Covestro and Evonik are very similar.

	Process summary	Product details	Benefits	Drawbacks	Input flexibility	Polyol output ¹	Amine output ¹	Overall output quality ²
	<ul style="list-style-type: none"> Acidolysis/glycolysis No phase separation 	Polyol containing isocyanate originated functions	<ul style="list-style-type: none"> + Small local plants possible 	<ul style="list-style-type: none"> - Low product quality - Limited recycled product content 	 High: low pre sorting needed	 240% , of which 40% is recycled polyol	 N/A	 Re-polyol with inferior properties
	<ul style="list-style-type: none"> Acidolysis/glycolysis No phase separation 	Polyol containing isocyanate originated functions	<ul style="list-style-type: none"> + Small local plants possible 	<ul style="list-style-type: none"> - Low product quality - Limited recycled product content 	 Medium: pre-sorting needed	 200% , of which 50% is recycled polyol	 N/A	 Re-polyol with inferior properties
	<ul style="list-style-type: none"> Hydroglycolysis Phase separation without solvent extraction 	Separate recovery of amines and polyol with improved costs	<ul style="list-style-type: none"> + High quality + Enables high recycled content 	<ul style="list-style-type: none"> - Requires large plant capacities and TDI production integration 	 Low: extensive pre sorting needed	 50% , of which ~100% recycled polyol	 20% (raw TDA)	 Both polyol and amine of relatively high quality
	<ul style="list-style-type: none"> Hydrolysis Solvent extraction using cyclohexane 	Separate recovery of amines and polyol	<ul style="list-style-type: none"> + High purity + Enables high recycled content 	<ul style="list-style-type: none"> - Requires large plant capacities and TDI production integration 	 Low: extensive pre-sorting needed	 55% , of which ~100% recycled polyol	 25% (raw TDA)	 Both polyol and amine of relatively high quality

1. Output as rProduct mass % compared to EoL foam introduced to the process. Circles refer to recycled content within polyol output. Based on patents and assumptions

2. Challenging assessment of output quality based on interviews with process experts and (partially) the companies themselves

Sources: desk research, SuP database analysis, expert interviews, competitor patents; Dow: DE102016122275A1, WO2022074184A1, Repsol: DE19512778C1, DE102013106364A1, Covestro: WO2022171586A1, Evonik: WO2022042910A1; EoL: End of life





 low  high

Competitive overview – Recycling costs

Pre-read

From a cost perspective, Covestro is far superior over Evonik. Consequently, Covestro's process is the best, both in terms of technology and price.

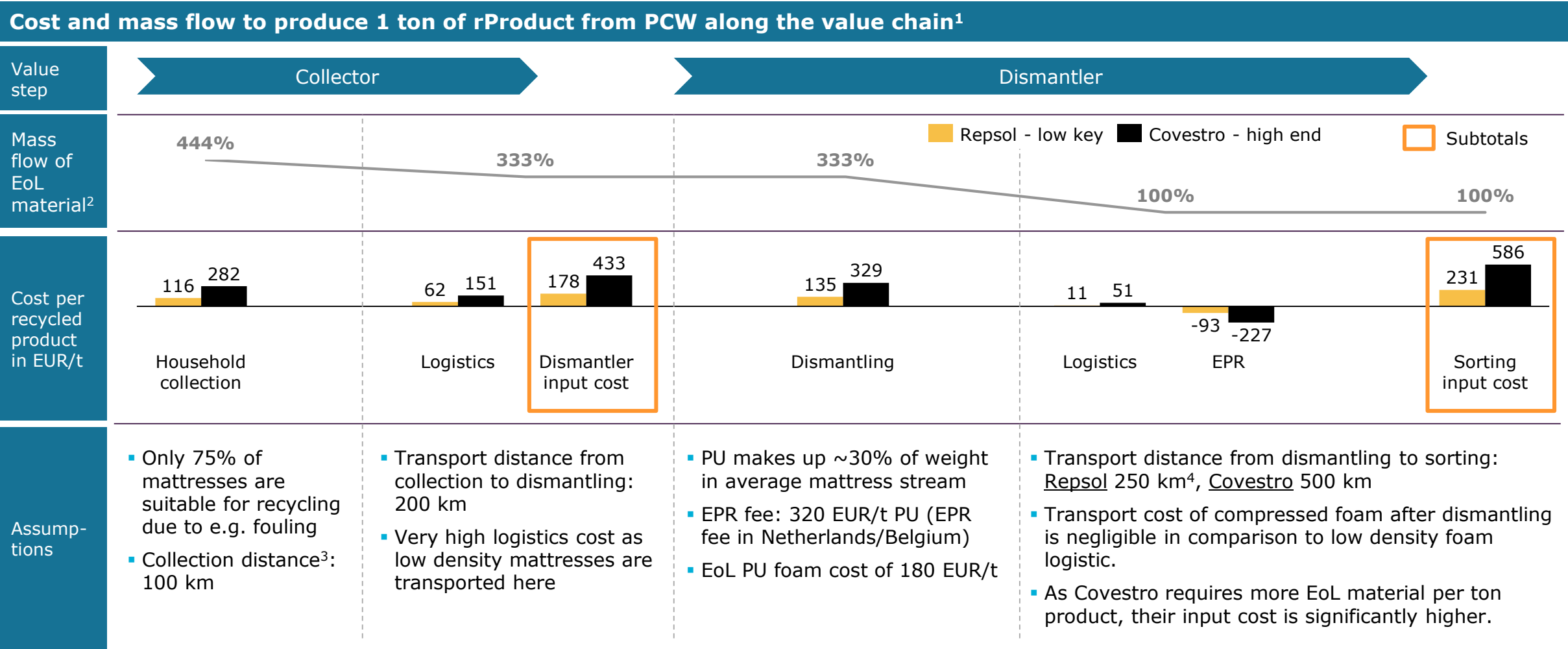
All numbers in EUR/t rProduct

	Input capacity /plant	Reagents	Labor	Utilities	Waste treatment	De-preciation	Others	Overall cost
 DOW	2 kt	831	143	10	5	392	320	1,701
 REPSOL	2 kt	1,050	171	9	5	417	350	2,002
 covestro	20 kt	183	49	56	76	224	173	761
 EVONIK Leading Beyond Chemistry	20 kt	1,267	49	193	273	236	255	2,272

Sources: desk research, SuP database analysis, expert interviews, competitor patents; Dow: DE102016122275A1, WO2022074184A1, Repsol: DE19512778C1, DE102013106364A1, Covestro: WO2022171586A1, Evonik: WO2022042910A1; EoL: End of life

Total costs along the value chain (1/2)

Covestro has 2.5x higher input costs before sorting compared to Repsol, as the process relies purely on PCW and has higher sorting losses.



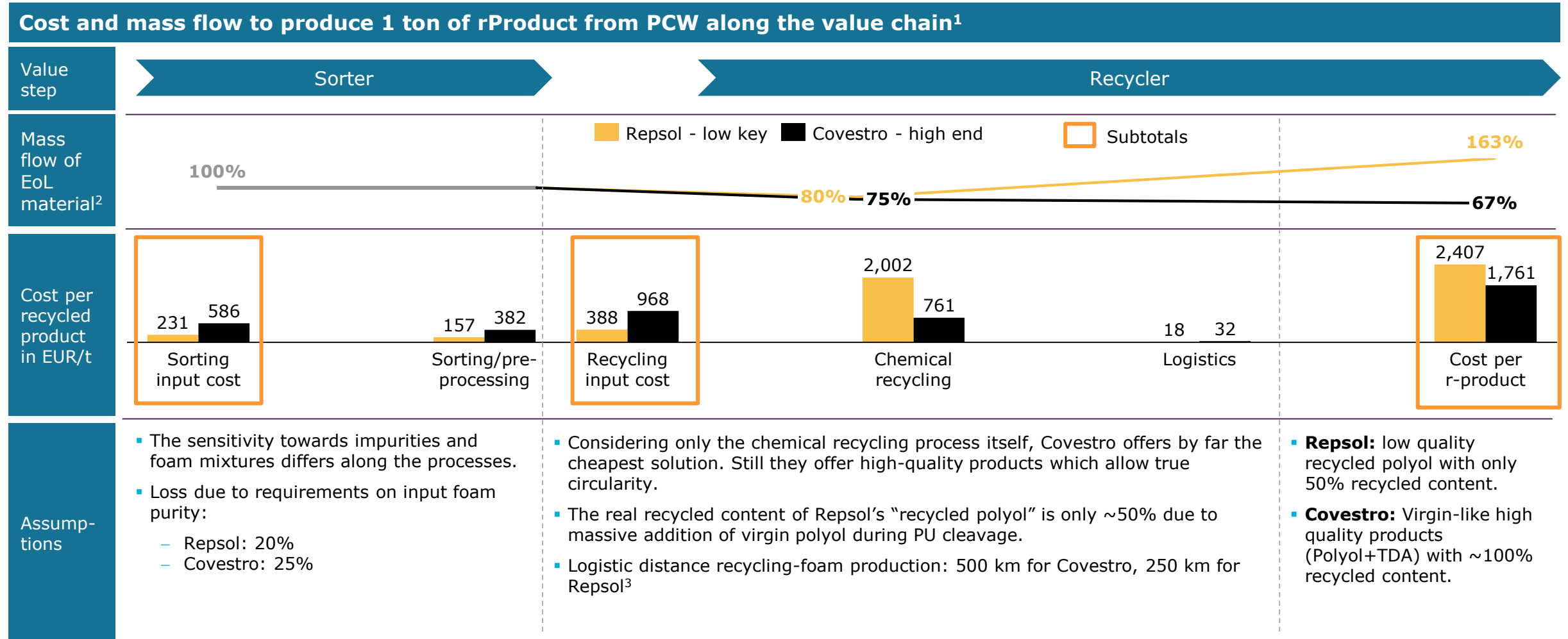
1. Most relevant process selected for each high-end and low-end chemical recycling; 2. 100% relates to mass of EoL PU foam; 3. Distance a truck has to drive until it is full; 4. Able to operate more decentralized

Sources: Sup desk research, interviews & analysis; EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste

Total costs along the value chain (2/2)

Pre-read

Despite the inferior input costs, Covestro's process is significantly cheaper due to the superior chemical recycling process leading to a 30% cost advantage over Repsol.



1. Most relevant process selected for each high-end and low-end chemical recycling; 2. 100% relates to mass of EoL PU foam; 3. Able to operate more decentralized

Sources: Sup desk research, interviews & analysis; EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste

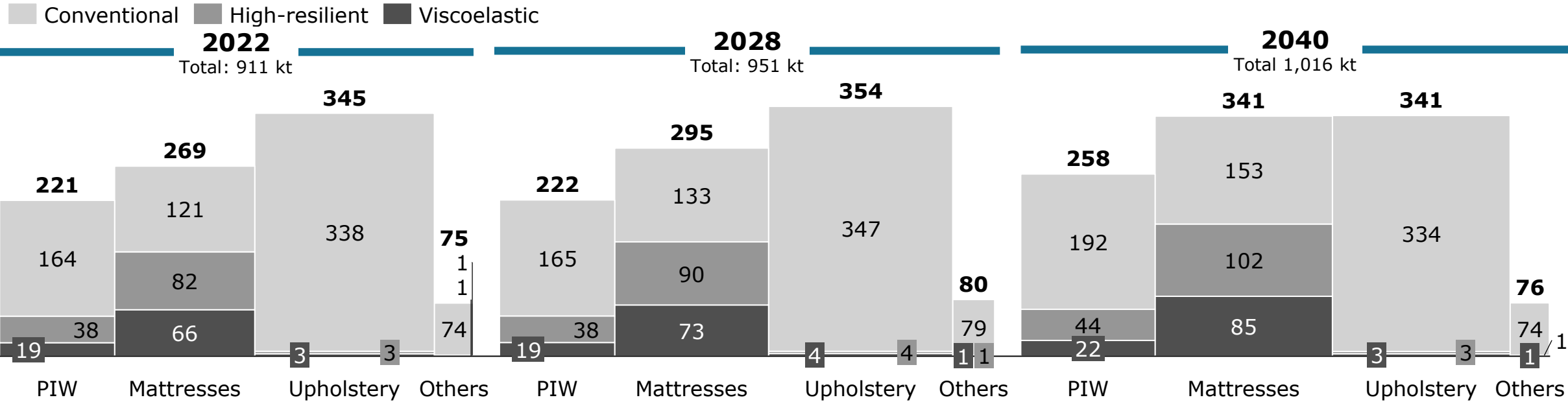
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EoL foam market – by application and foam type

Pre-read

EoL PU market is dominated by conventional upholstery foam. Significant numbers of viscoelastic and high-resilient foam is coming only from mattresses.

PU foam reaching EoL in kt from 2022-2040 by segment and foam type



- The maximum EoL PU volume summarizes all kinds of PU foam reaching the end of lifetime in each respective year. Factors taking into account the **material volume which is realistically collected and real availability for chemical recycling are not included.**
- Upholstery foams make up the largest single share of the foam market. In the long term, the **upholstery volume** is expected to **remain stabile** due to decreasing population on side and increasing spending on the other side.
- **Mattresses** show the largest **growth** potential. This can be attributed mainly to a **growing share** of PU foam in average mattresses as well as increasing relevance of PU mattresses.¹

1. Under the assumption that there will be a successful solution for PU waste treatment and recycling targets can be met

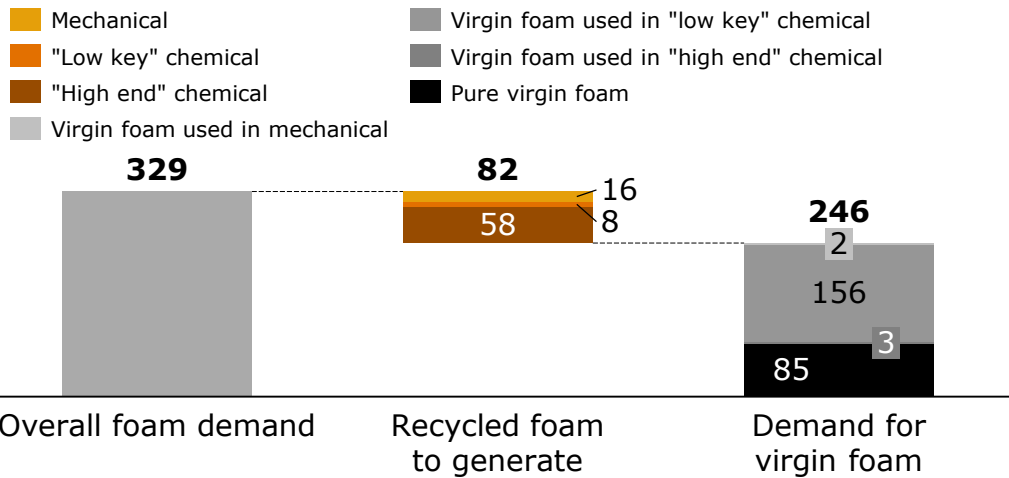
Sources: SuP desk research, consumer survey & interviews, EUROPUR, CSIL, Eurostat, UN World Population Prospects 2022; EoL: End of life; PIW: Post industrial waste/by-product

Impacts on PU industry due to increasing recycling rates

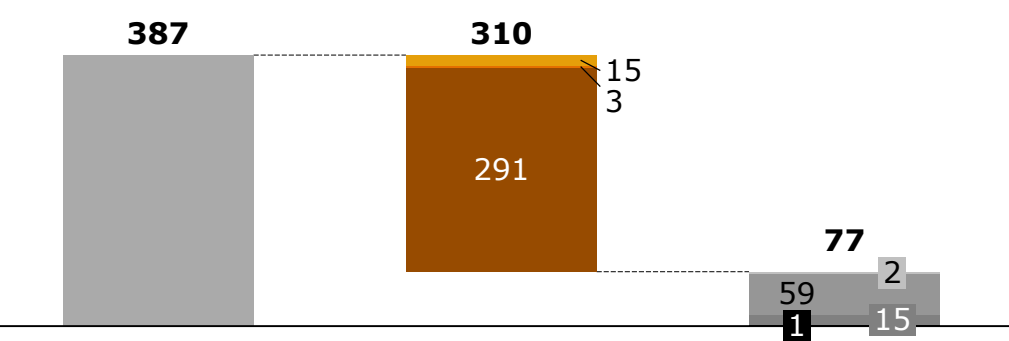
With expected increase in recycling targets for PU foam, the industry needs to adapt production capacity for virgin products and support the supply chain of PCW foam.

Virgin PU demand for mattresses based on recycling rate

2028: 25% recycling target



2040: 80% recycling target



Highlighted challenge



Demand for recycled PU raw materials will affect market for virgin products



Without incentives & proper recycling infrastructure demand for recycled raw materials may not be met



Inability to manage changes in PU demand / supply may harm the whole industry

Description

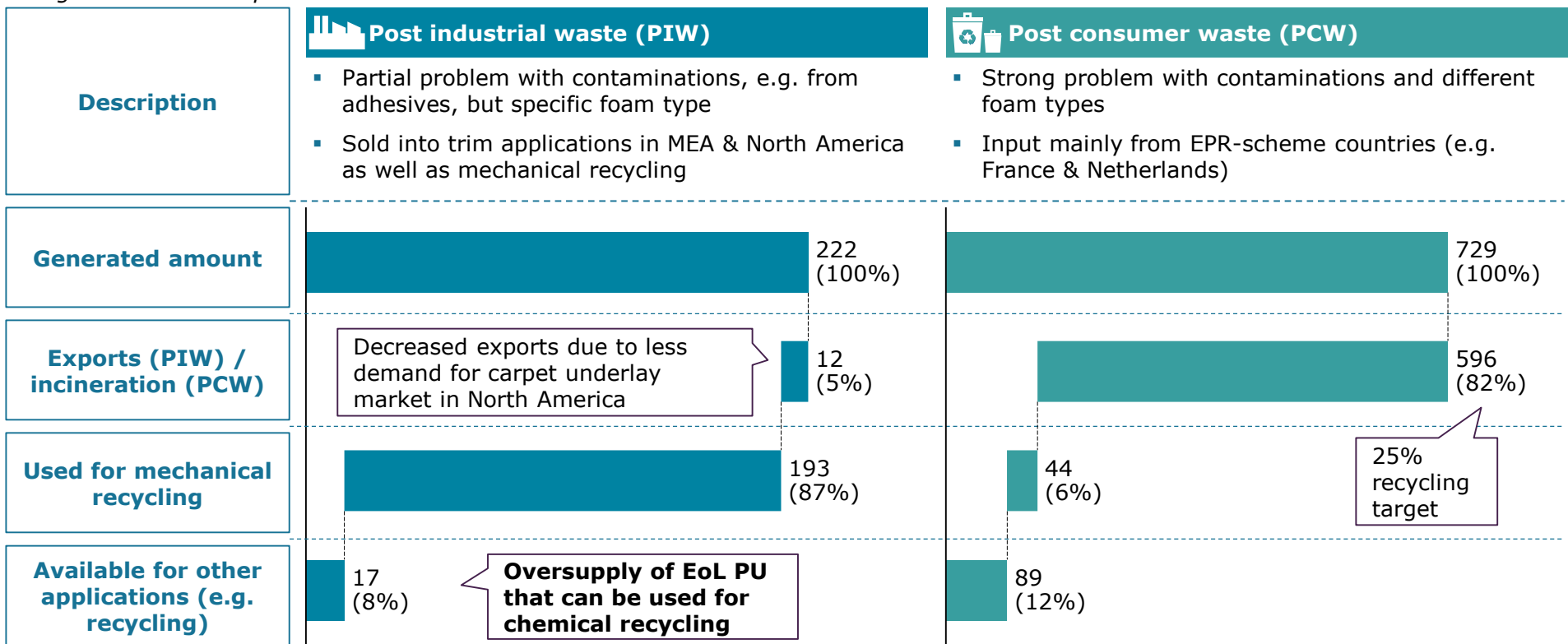
- Despite increasing PU demand the current capacity utilization for virgin raw materials could decrease to the point of margin squeezes and further capacity reduction
- Similar market dynamics can be observed for plastics for packaging with recycle prices exceeding those for virgin products
- Similar to other polymers an increasing demand for recycled raw materials is expected even without recycling targets
- Collection and sorting of PCW foam needs to be accelerated with EPR schemes
- Hence, there is a risk of supply shortage for PCW PU foam at least in mid-term
- The PU industry will likely need to adapt to lower demand for virgin materials with production capacity adaption.
- At the same time, the industry needs to support the supply chain for PCW foam to keep up with demand for recycled PU foam

Sources: desk research, interviews, analysis & SuP expertise, EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste; EPR: Extended producer responsibility

PIW vs. PCW – available amounts & prices

Due to decreasing exports of PIW until 2028 a high amount of 106 kt of EoL PU becomes available for chemical recycling to fill the capacities until PCW is widely available.

All figures reflect European numbers in kt in 2028



I would highly recommend to start with PIW in the processes as foams are quite complex requiring a control of input streams. With PIW, you know the composition of your input, making process control much easier. As soon as you gain full control of your process under these circumstances, you can start targeting the more difficult PCW. In addition this approach will help you to bridge the time until PCW channels are established.

- Recycling plant design engineer

We used 75% PIW and 25% PCW but are not at 50/50 as prices and output [for PCW] is stabilizing.

- Federal EcoFoam

Strategic implications:

- Market dynamics** will lead to an **oversupply of PIW** in the next years.
- PIW high quality** input material, **almost free of contaminations and widely available**, making it an attractive product for both recycling technologies.
- PIW can be seen as **substitution for sorted PCW** giving it a cost advantage were dismantling and sorting cost are high.
- However, **PIW may not be considered a viable solution to fully close the PU loop.**
- It can be seen as **bridge to fill the recycling stream until PCW becomes available** on a large scale with its **respective infrastructure.**

Sources: desk research, interviews, analysis & SuP expertise, EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste

EoL foam market – by treatment

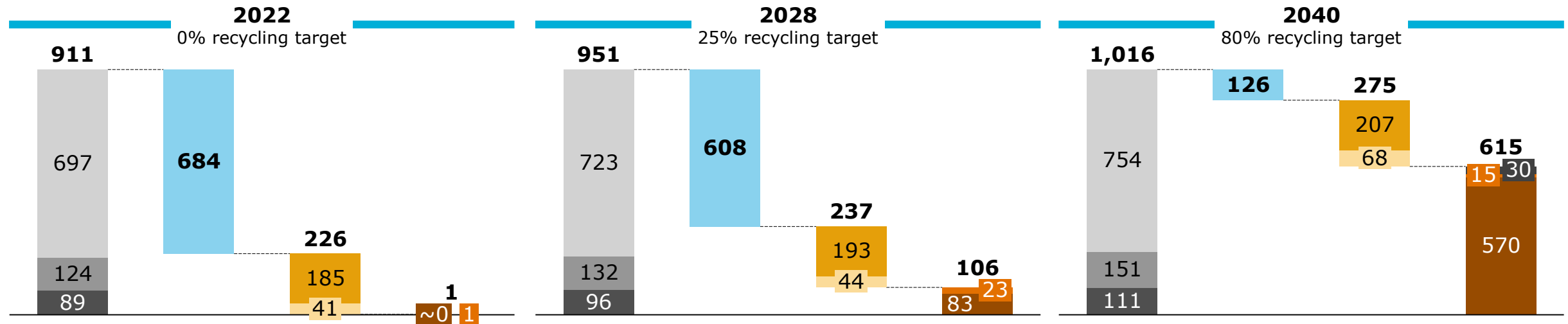
Pre-read

Only with a significant increase in “high end” chemical recycling of PU foam, 25% recycling content target can be reached in 2028. “Low key” chemical recycling is no solution long-term.



EoL foam market in kt from 2022-2040 by treatment

Conventional EoL foam Viscoelastic EoL foam Pyrolysis Mechanical recycling from PCW "High end" chemical recycling
High-resilient EoL foam Incinerated/Landfilled Mechanical recycling from PIW "Low key" chemical recycling



- The **realistic foam volume** takes into account **factors like waste collection and availability of dismantling and pre-treatment infrastructure** required for chemical recycling.
- As **waste collection** in the relevant segments is **barely developed** and **necessary pre-treatment for chemical recycling plants is not available** in significant scale today, ramp up will proceed slowly. Only low chemical recycling capacity is currently available.
- In **2028**, a **relevant share of mattresses has to be chemically recycled** in order to reach anticipated **EU recycling targets**. Therefore, the share of mattresses being available for chemical recycling is expected to increase if the barriers (e.g. improved collection & dismantling) can be overcome.
- The development of the **upholstery waste value chain will follow** with a **delay of a couple of years**. In **2040** however, **all segments will be able to contribute a significant share to chemical recycling after waste collection and dismantling schemes are established**.

Sources: SuP desk research, consumer survey & interviews, EUROPUR, CSIL, Eurostat, UN World Population Prospects 2022; EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste

Acceptable raw material selling price

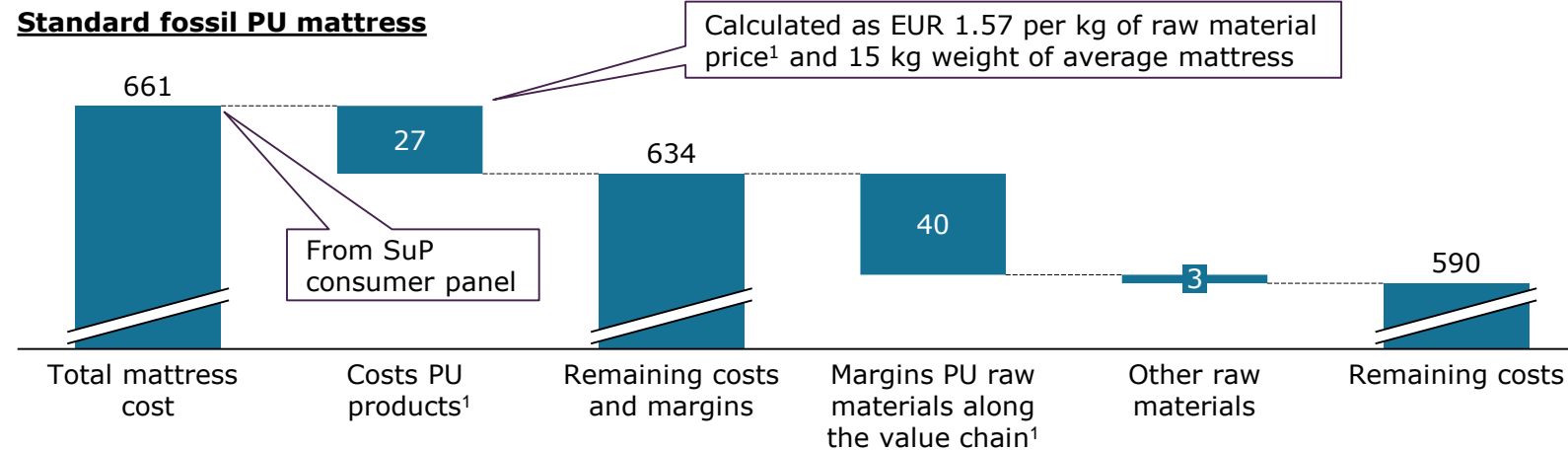
Pre-read

The consumer willingness to pay 6% more for a sustainable mattress translates to a 50% higher acceptable price for PU raw materials.

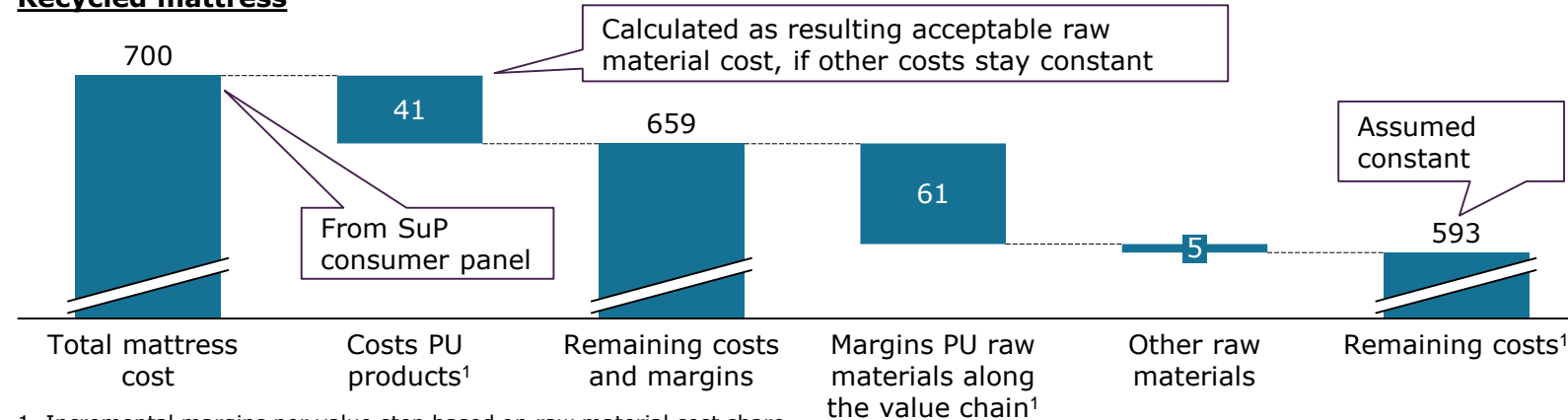


Acceptable recycled raw material costs from consumer perspective in EUR per mattress

Standard fossil PU mattress



Recycled mattress



1. Incremental margins per value step based on raw material cost share

2. Analyzed countries include France, Germany, Netherlands, Poland and Sweden

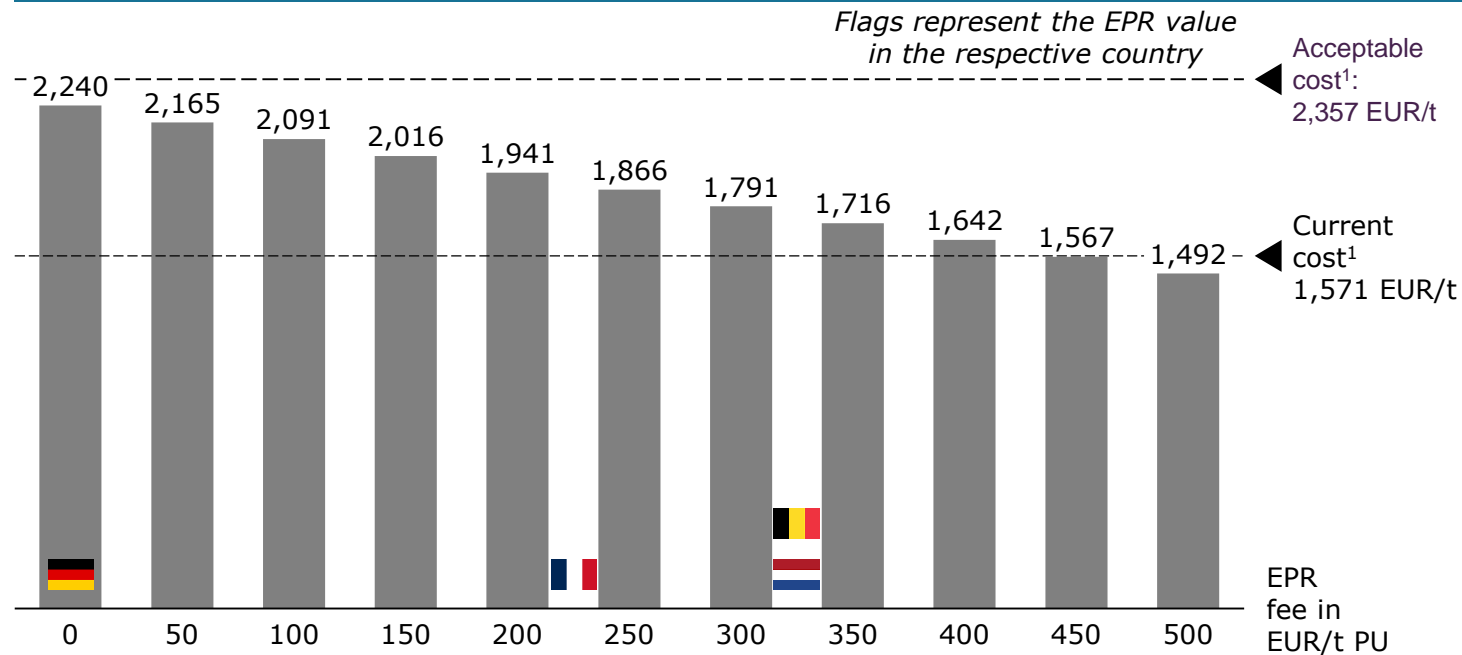
Sources: SuP analysis based on consumer panel and financial reports of key players

- In the **SuP consumer survey** an average **price per mattress of EUR 661** was stated for the analyzed European countries².
- In case of a **recycled / sustainable mattress** a price of **EUR 700** per mattress was **stated to be acceptable** (corresponds to **6% per mattress**).
- Considering **constant remaining costs and percentage of margins to stay constant**, this allows the absorption of a **raw material cost increase from EUR 27 per mattress to EUR 41**.
- This corresponds to a price potential **increase of 50% or EUR 2.36 per kg instead of EUR 1.57**. Thereby the willingness to pay opens up potential to absorb possible price increases.

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EPR fees bring recycled PU foam close to virgin material costs. Hence, EPR fees are crucial to enable quick market penetration of recycled PU foam.

 Foam material cost with 100% recycled content with varying EPR fee in EUR/t



Assumptions

- Household collection distance²: 100 km
- Transport collection to dismantling distance: 200 km
- Transport distance dismantling to recycling: 500 km
- Process based on Covestro technology

1. Current cost include virgin foam material cost (polyol & TDA) of 1,571 EUR/t; acceptable cost include an acceptable price increase of 50% for foam material
 2. Distance a truck has to drive until it is full

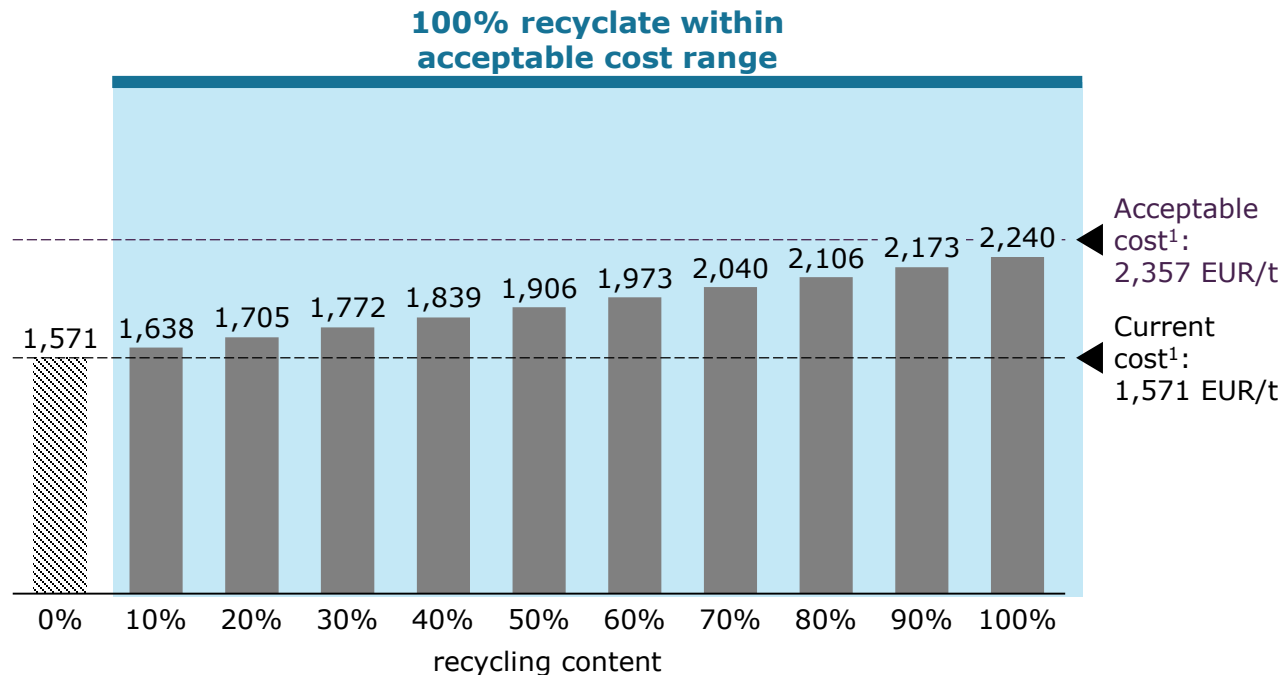
Sources: SuP desk research, interviews & analysis; EPR: Extended producer responsibility

- As recycled product costs are higher compared to virgin material costs, **raw material costs would increase** for foamers if there is no additional financial support.
- Taking into account only virgin material costs, an **EPR fee ~450 EUR/t** becomes necessary in order to reach a **break-even** between virgin material as well as EoL cost and recycled material cost.
- EPR fees of ~300 EUR/t** appear to be realistic in current discussions. At this value, material cost for a foam made out of 100% recycled feedstock would be around 200 EUR/t higher compared to virgin.
- If the **consumer willingness to pay for sustainable products (around 50%)** is taken into consideration as well, profitability could easily reach volumes of several hundred EUR/t.
- Even without EPR**, recycled foam cost are within the **acceptable** price range.

Dependency of foam costs on recycled content

Even without EPR fee, chemical recycling is competitive taking 50% increased willingness to pay for sustainable products into consideration.

 Foam material cost with varying recycled content in EUR/t without EPR fee



Assumptions

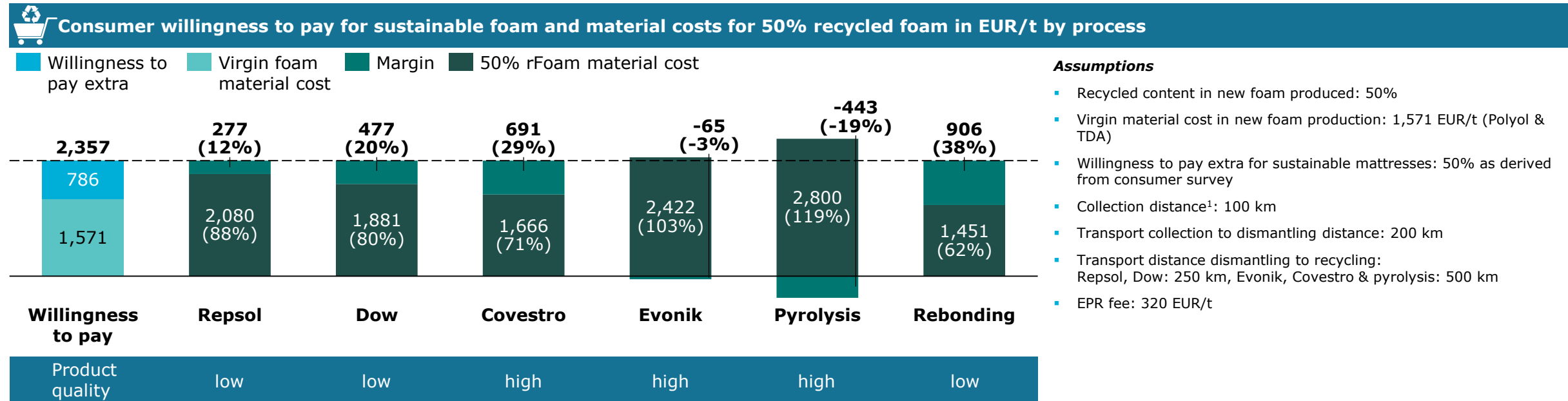
- Household collection distance²: 100 km
- Transport collection to dismantling distance: 200 km
- Transport distance dismantling to recycling: 500 km
- Process based on Covestro technology

- As recycled product costs are higher compared to virgin material costs, **foam costs increase with higher recycled contents**.
- Without EPR fee, chemical recycling** remains **more expensive** compared to virgin material.
- A **price increase of 50%** for foam material cost is **considered acceptable** for production of sustainable mattresses. This **enables penetration of recycled products** even up to **100%**.
- However, not relevant for the foam producer, there are **further aspects** that make **recycled PU foam commercially more attractive** along the value chain:
 - Savings for incineration of the mattress of EUR 150 per ton
 - Savings for CO₂ certificates
 - Potential subsidies

1. Current cost include virgin foam material cost (polyol & TDA) of 1,571 EUR/t; acceptable cost include an acceptable price increase of 50% for foam material
2. Distance a truck has to drive until it is full

Sources: SuP desk research, interviews & analysis; EPR: Extended producer responsibility

Covestro appears to offer the most attractive technology with a combination of high quality products and potential for a healthy margin.



- Covestro** offers the only process close to **profitability** delivering **high quality** products without limitations in recycled contents.
- The **Dow** process shows most potential to be profitable on its own for chemical recycling. The potential to use polyol recovered from the Dow process in new foam is however limited. It is questionable if a **recycled content of 25%** is realistic without limits in performance.
- Repsol** offers interesting potential, but the utilization of its product in new foam production is **limited to ~20-30%** as well.
- The **Evonik process and pyrolysis are too expensive** in order to be economically interesting.
- In addition, pyrolysis doesn't deliver molecular products to be reused directly in the same applications.
- Rebonding** is the most interesting option from an **economical** point of view. The **applications** which can utilize rebonded foam in mattresses are however **limited**. It is unlikely that a recycled content of 50% could be reached without limitations in quality.

1. Distance a truck has to drive until it is full

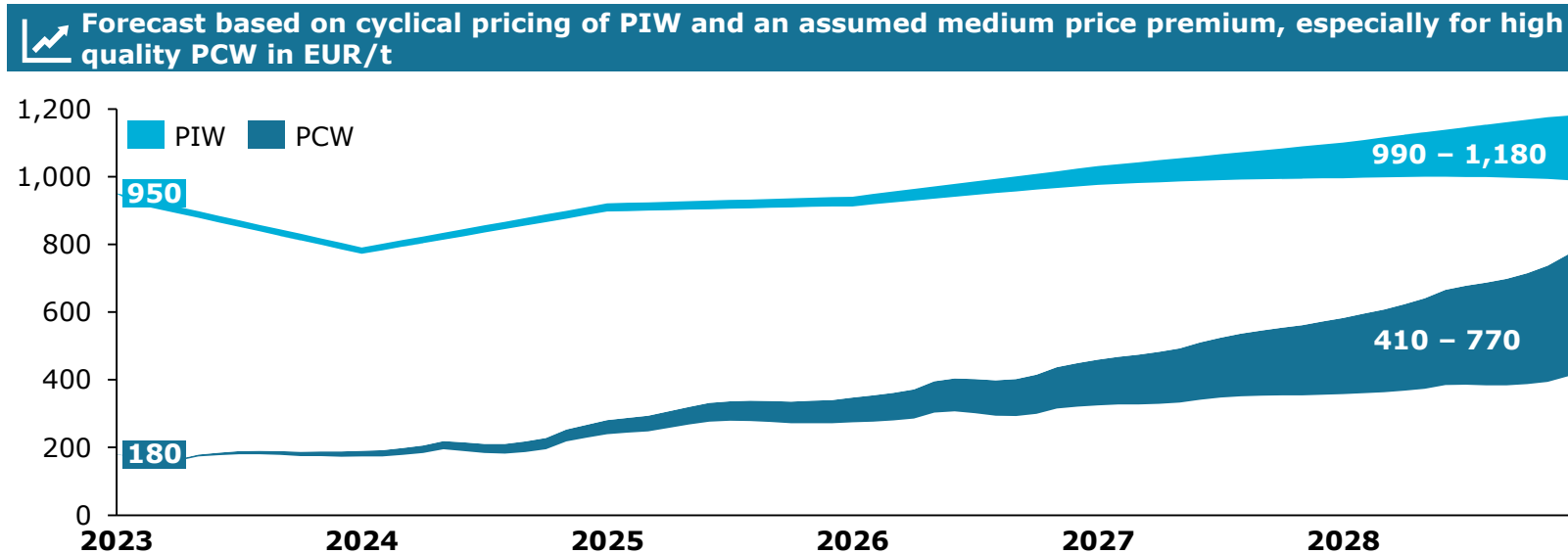
Sources: SuP desk research, interviews & analysis, EoL: End of life

PIW vs. PCW – price forecast

Pre-read

With or without EPR scheme the European prices for PIW and PCW are expected to see a strong increase until 2028, driven by higher demand for recyclates.

Both scenarios in appendix



Price drivers for PIW:

- Increasing demand for mechanical recycling.
- Overseas exports expected to decrease over the next years.
- This leads to a similar growth rate compared to PCW.

Price drivers for PCW:

- Stable to slightly increasing demand for mechanical & chemical recycling.
- New dismantlers coming online.

A 2.5% annual reduction of carbon footprint is sufficient to reach the Paris Agreement. (...) using PIW is a first step as it is much cheaper than virgin material.

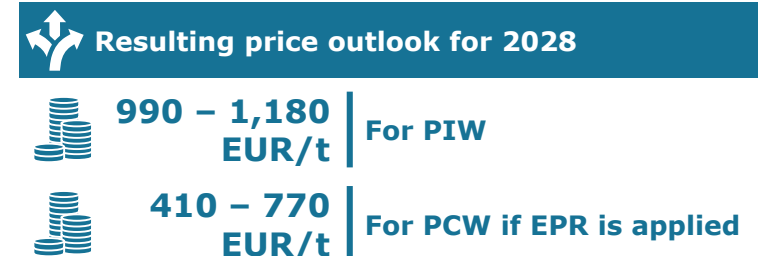
- VITA Group

With good infrastructure the PCW demand will increase over the next years and so will the prices, keeping PIW attractive.

- Mechanical recycler

Strategic implications:

- With or without the effect of EPR, prices for PCW is expected to be **lower than PIW in 2028**.
- However, the **difference is expected to decrease** over time due to the **increasing demand for high quality PCW** from EoL PU driving the recycled premium price.
- Long term price development** highly dependent on **PCW vs. PIW demand** and the ability of the **recycling infrastructure to keep up with the respective output**. EPR is the key to accelerate development of infrastructure and enable "high end" recycling, which is required to reach upcoming recycling targets.
- Based on analysis and expert interviews and similar developments (e.g. rPET vs. PET), **SuP is expecting the price to be in the upper range of the forecast**.



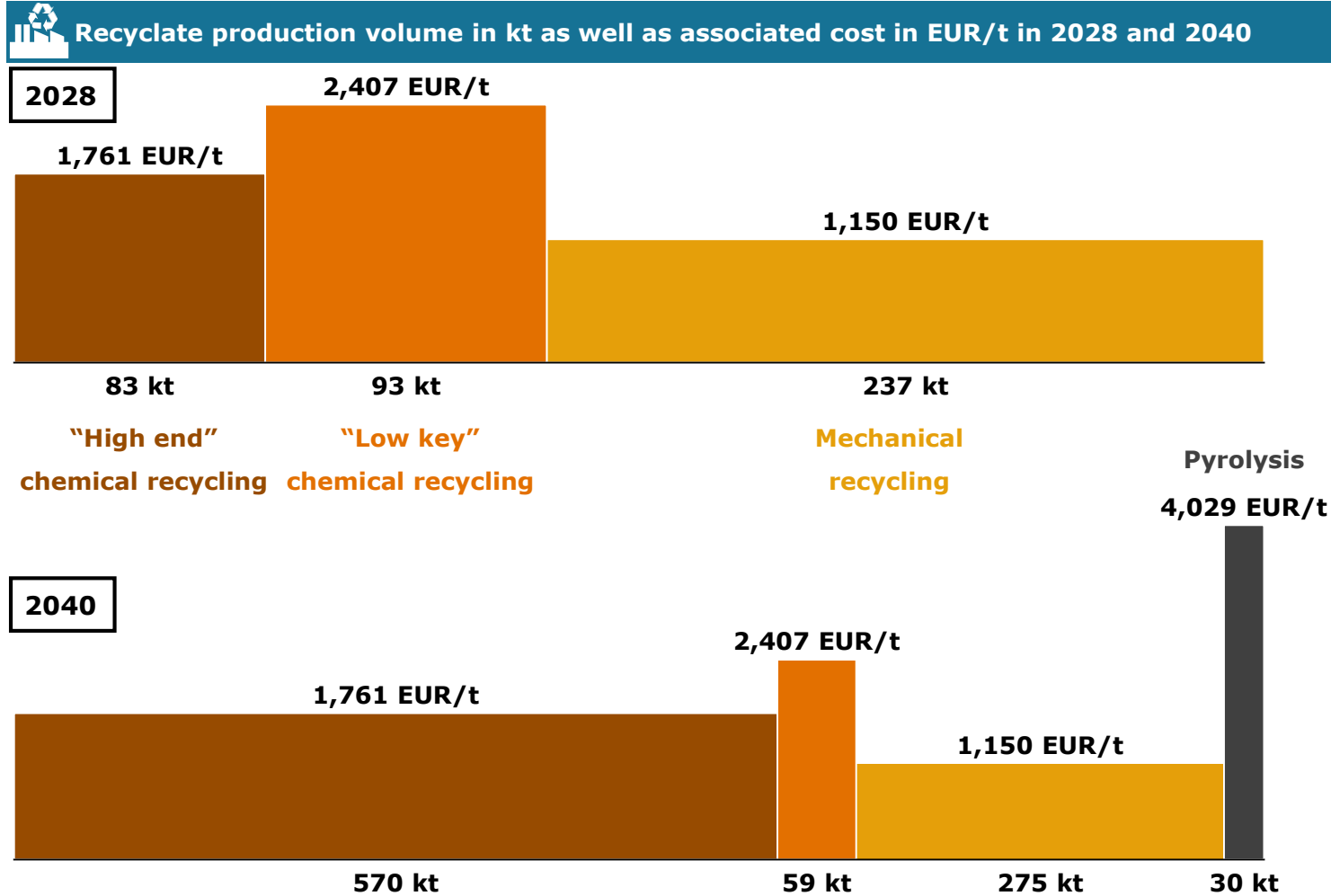
Sources: desk research, interviews, analysis & SuP expertise; EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste; EPR: Extended producer responsibility

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Cost plots (1/2)

Pre-read

Mechanical recycling as the cheapest and already established solution will still make up the majority of the recycled product market by 2028.



Cost assumed to remain constant over the years

Sources: desk research, interviews, analysis & SuP expertise, EoL: End of life

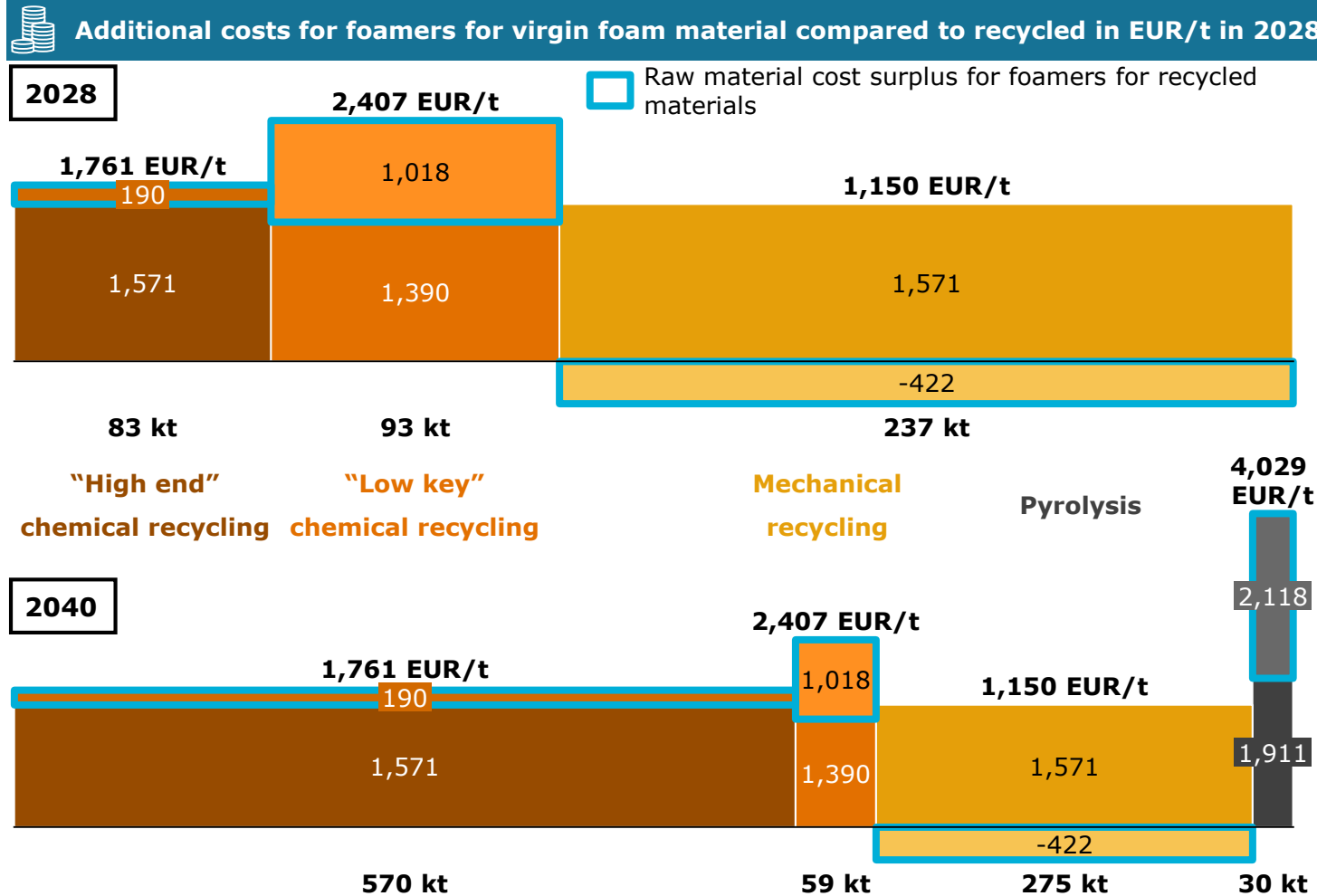
Technology outlook:

- **Rebonded foam is already established** and will therefore keep a strong position, especially if it can replace virgin foam e.g. in mattresses.
- **"Low key"** chemical recycling is currently entering the market and will remain a relevant **alternative for cheap solutions**.
- **"High end" chemical recycling will need some time** for ramp up in order to establish required EoL solutions like collection and sorting infrastructure.
- **Pyrolysis is considered less suitable** for soft foam and will need time to scale up.

Cost plots (2/2)

Pre-read

In 2040, “high end” chemical recycling will have become the most relevant technology as it is the only one to deliver high quality products for 100% recycling.



Cost assumed to remain constant over the years

Sources: desk research, interviews, analysis & SuP expertise, EoL: End of life

Technology outlook:

- **Rebonded foam is most price competitive solution**, but is a **completely different product**. It will be the first choice to replace small quantities wherever possible.
- **“Low key” chemical recycling offers flexibility with small, decentralized facilities** and will keep its position between mechanical and “high end” chemical recycling.
- **“High end” chemical recycling is the only solution to achieve true circularity.**
- **Pyrolysis** is very expensive, which is why it will remain a **niche** solution.

Strategic implications:

- While mechanical and “low key” chemical recycling are very competitive for limited applications, the **focus on “high end” chemical recycling** is the best solution to position as driver of **circularity** and secure a relevant market in the long term.

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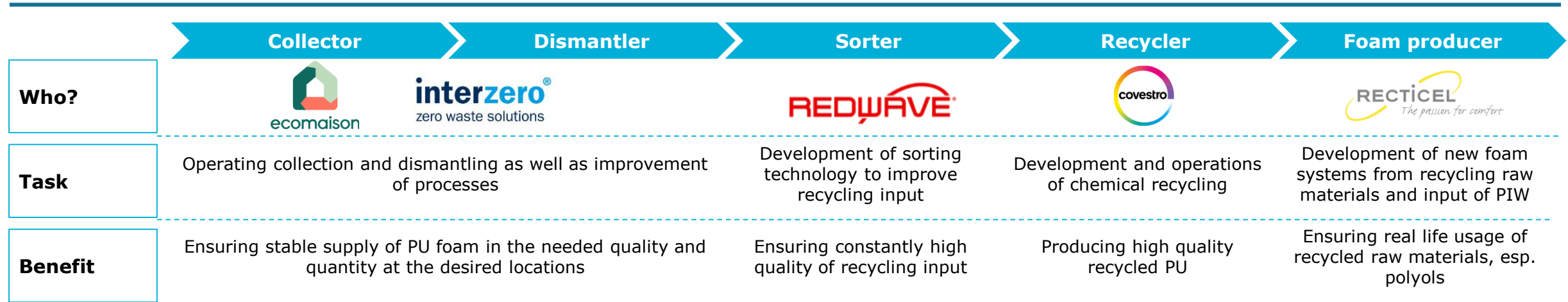
Partnerships in EoL PU supply chains

Pre-read

To succeed in PU foam recycling, it is highly advisable to engage in strong partnerships along the value chain to develop the supply of EoL foam from collectors, dismantlers and sorters.



Example of partnerships along the value chain to enhance PU foam recycling



- **Collaborations along the value chain** can mitigate or solve issues **to implement circularity for PU foam**.
- Such **collaborations** have **proven** themselves **successful** in **packaging recycling**, e.g.: Eastman / Interzero / PepsiCo.
- **Especially collection, dismantling and sorting** is **crucial to** the **success** of recycling business at scale.
- **Large stakeholders** in the market (e.g. IKEA or associations) explicitly **ask for large chemical companies** to be **active along the supply chain** in order to **give investment security to small players**, esp. collectors and dismantlers.



We see ourselves in the position to improve recycling of PU to support our statements for sustainability and to ensure that PU products can still be sold once regulations are in place. We see ourselves not necessarily as recycler. We would love to see the big chemical players step up and give the value chain the safety to invest into collection and dismantling.

- IKEA

The BASFs, Covestros and alike need to move ahead and give the industry the safety to invest. Otherwise, we have big concerns PU will stay as relevant as it is right now.

- Mattress association Germany

Sources: desk research, interviews, analysis & SuP expertise; EoL: End of life; EPR: Extended producer responsibility

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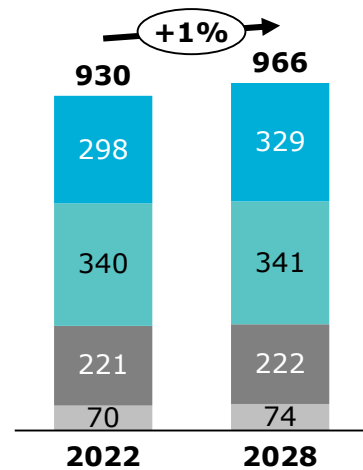
Management summary (1/3) – Trends & developments in the EU PU (recycling) industry

Pre-read

Stable demand for PU, actions taken and planned by brand owners and law makers creating need for chemical companies to become active and counter eroding virgin demand.

European flexible PU demand in kt

Mattresses PIW
Upholstery Others



Stable demand for PU in mattress & upholstery market with intention of brand owners and consumers to stick to the technology.

"We strongly believe in PU mattresses and want them to stay. But for this actions need to be taken" – IKEA

"We believe PU mattress share stays like this, but only if the industry gets recycling done" – German mattress association

"We believe PU mattress share stays like this, but only if the industry gets recycling done" – German mattress association

EPR scheme for EoL PU



Increasing **drive towards circularity** by brand owners and law makers with **high certainty of EPR scheme** implementation, already in place in some countries.



Currently **majority of mattresses and upholstery is incinerated** after their lifetime of **~10 years** and thus their raw material value is lost.



Design for recycling gains momentum as **major brand owners look for solutions** around recycled materials and their implementation.



3 - 9% price surplus for sustainable mattress acceptable for consumers

Willingness to pay for sustainable solutions by consumers is **given but yet low** (3 – 9% (20 – 55 EUR per mattress) according to consumer survey). Retailers observe **increasing willingness to pay with higher awareness for circularity**.

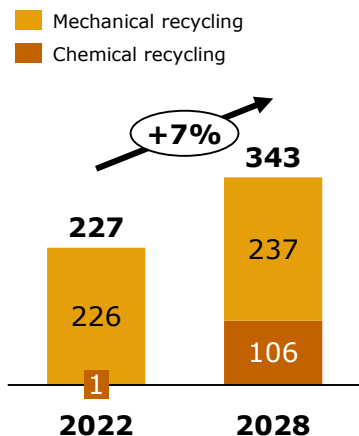
Virgin polyol capacity	→	→
Virgin polyol demand	→	→
Virgin TDI capacity	→	→
Virgin TDI demand	→	→
rPolyol & rTDI demand	→	→
	2028	2040

Constant capacity for polyol & TDI with expected **lower virgin demand** and higher demand for **recycled polyol & TDI** long term to put **pressure on the PU industry?**

Sources: desk research, interviews, analysis & SuP expertise; PIW: Post industrial waste/by-product

Upcoming regulatory recycling targets can only be met by chemical recycling. The build-up of strong partnerships should be considered to enable market entry.

European rec. PU demand in kt

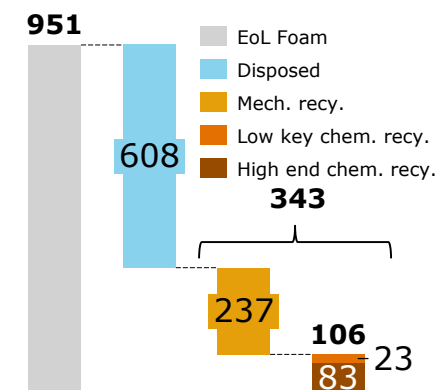


106 kt market for chemical recycled PU in 2028

To comply with expected 2028 recycling targets of 25%, the total market for recycled PU will grow by 7% p.a.

At the same time chemically recycled PU needs to grow by factor 100x.

European PU rec. structure in kt in 2028



Only with new recycling technologies that offer up to 100% recycling content, the EU targets can be met

“High end” chemical recycling like offered from BASF, Covestro and Evonik is needed.

Technologies from Dow and Repsol will phase out.

Production cost for PU foam raw material in EUR/t



A recycling process like Covestro’s is in range with virgin PU foam raw materials (70% polyol + 30% TDI)

Other chemical processes like Repsol’s have far higher costs at significantly inferior quality.

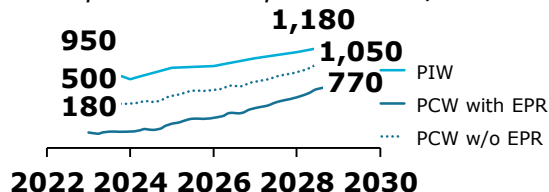
PU raw material sales price in EUR/t



Even without EPR schemes chemical recycling can still be acceptable in terms of PU raw material pricing

Considering a 50% higher willingness to pay on raw material level¹ according to consumer surveys, chemically recycled PU materials would be still 5% cheaper than acceptable.

European EoL PU price in EUR/kt



Lack of available supply will drive the price for PCW and hence recycled PU raw materials

Looking at alternative recycling markets like rPET, the lack of supply of waste and increasing demand led to a significant shortage and spike in pricing.



= success?

To ensure stable PCW supply and stabilize cost levels, partnerships with collectors and retailers are important






To stimulate investments in sorting & dismantling and getting stable access to PCW, investments and partnerships with key players in the value chain are important, e.g. IKEA or Veolia.

1. Acceptable price based on willingness to pay 6% more for a mattress with recycled content resulting in a 50% higher PU raw material price, taking into account an assumed 20% margin for PU raw materials

Sources: desk research, interviews, analysis & SuP expertise; EoL: End of life; EPR: Extended producer responsibility; PIW: Post industrial waste/by-product; PCW: Post consumer waste

The recommendation is to enter the market PU recycling with a technology similar to Covestro and engage in the whole supply chain to ensure supply quality and quantity.

Strategic implications

-  Both mechanical and chemical recycling will have a **strong impact** on the PU (raw materials) industry.
-  **Oversupply** of polyols (and subsequently TDA and TDI) together with **favoring of recyclates** over virgin materials might drive need to adapt the production setup.
-  Market still in an early stage with **high uncertainty, yet huge long term potential**, especially for large integrated players.
-  **Close collaboration** with external partners along the value chain needed to create ecosystem with good input material quality, short distances and thus lower costs.
-  **Creation of awareness** of brand owners, consumers and law makers together with education about laminations and additional cost needed.

Recommendations / next steps

-  Bring recycling technology to **maturity** and select **partnerships** / technologies to fit the technology's need.
-  Set up **strategic alliance** with partners along the value chain and create incentives to invest collection, dismantling and sorting.
-  Using of influence to **create awareness** for the topic and on regulation to create needed standards (e.g. EPR scheme).
-  Focus on **PIW as input material first and then switch to PCW**, once the proper recycling ecosystem and technology is set up.
-  **Consider multi layer business models** with several options for possible recycling technologies depending on collection possibilities, costs per region, subsidies etc.
-  Consider first activities close to/ in countries with existing infrastructure to **be present in the market** and share creation of recycled PU ecosystem.

Sources: interviews & SuP expertise

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Overview of contacted companies (1/2)

Pre-read

Over the course of the project SuP conducted 85 interviews with market experts and leading players along the value chain.

#	Company	Location	Segment
1	APE TeK	IT	Recycling companies
2	Mattress Tek	UK	Recycling companies
3	Schmitz Foam	NL	Processing companies/ foamers
4	Recticel	BE	Processing companies/ foamers
5	Fema Industry	IT	Processing companies/ foamers
6	PCM Engineering	IT	Processing companies/ foamers
7	KSM Mtec	DE	Processing companies/ foamers
8	Sekisui Kasei	EU	Processing companies/ foamers
9	Neveon	AT	Processing companies/ foamers
10	Pahlke Schaumstoffe	DE	Processing companies/ foamers
11	Vita Group	UK	Processing companies/ foamers
12	Foamplant	NL	Processing companies/ foamers
13	Sekisui Alveo	CH	Processing companies/ foamers
14	Berkosan	TR	Processing companies/ foamers
15	UFM United Foam Manufacturers	HR	Others
16	Wertstoffhof Hedelfingen	DE	Collecting companies
17	Wertstoffhof Mitte	DE	Collecting companies
18	Sperrmüll Augsburg	DE	Collecting companies
19	UNTHA shredding technology	AT	Collecting companies
20	UNTHA shredding technology	AT	Collecting companies
21	Matratzen-Allianz	CH	Others
22	Royal Auping	NL	Retailers/ brand owners
23	EUROPUR	BE	Others
24	Confidential	DE	Raw material producers
25	Recticel	DE	Processing companies/ foamers

#	Company	Location	Segment
26	Fachverband Matratzen-Industrie e.V.	DE	Retailers/ brand owners
27	Hilding Anders International AB	NL	Retailers/ brand owners
28	Confidential	DE	Recycling companies
29	Confidential	DE	Others
30	Confidential	EU	Raw material producers
31	H&S Anlagentechnik	DE	Recycling companies
32	Rummel Matratzen	DE	Retailers/ brand owners
33	Una Organic GmbH	DE	Retailers/ brand owners
34	Betten Knoll	DE	Retailers/ brand owners
35	Recticel International	NL	Retailers/ brand owners
36	VitaGroup	UK	Retailers/ brand owners
37	FederalEcoFoam	BE	Processing companies/ foamers
38	Bensons for Beds Charlton	UK	Retailers/ brand owners
39	JYSK	DE	Retailers/ brand owners
40	Recyclinghof / Incineration plant	DE	Recycling companies
41	Emma Matratze (subsidiary of Bettzeit GmbH)	DE	Retailers/ brand owners
42	John Lewis Home	UK	Retailers/ brand owners
43	used-design	DE	Retailers/ brand owners
44	XXXLutz	DE	Retailers/ brand owners
45	National Bed Federation	UK	Others
46	Galeria Karstadt Kaufhof GmbH	DE	Retailers/ brand owners
47	RAVENSBERGER Matratzen® - Fachgeschäft Frankfurt a.M.	DE	Retailers/ brand owners
48	IKEA Sweden	SE	Retailers/ brand owners
49	IKEA Germany	DE	Retailers/ brand owners
50	Retour Matras	NL	Collecting companies

Overview of contacted companies (2/2)

Pre-read

Over the course of the project SuP conducted 85 interviews with market experts and leading players along the value chain.

#	Company	Location	Segment
51	Victoria Group	UK	Others
52	Neveon	DE	Processing companies/ foamers
53	Laader Berg	NO	Processing companies/ foamers
54	Belvedere	UK	Others
55	Eurofed	EU	Others
56	Smart Materials	IT	Processing companies/ foamers
57	IKANO	PL	Recycling companies
58	Tempur	UK	Retailers/ brand owners
59	D&E Entsorgung	DE	Recycling companies
60	Confidential	DE	Others
61	Rampf	DE	Recycling companies
62	Confidential	ES	Recycling companies
63	D&E Entsorgung (via BASF)	DE	Recycling companies
64	Bundesumweltamt	DE	Association / market expert
65	Bundesumweltamt	DE	Association / market expert
66	Fachverband Matratzen-Industrie e.V. (former employee at Hülsta)	DE	Association / market expert
67	take away	DE	Association / market expert
68	Gemeinde Maastrich	NL	Collecting companies
69	Ingka Investments (IKEA)	NL	Retailers/ brand owners
70	Zero Waste France	FR	Association / market expert
71	Valdelia	FR	Others
72	Recyc-Matelas	FR	Recycling companies
73	ZAKB Wertstoffverwertung	DE	Recycling companies
74	Milieupark Kerkrade	NL	Recycling companies
75	Ingka Investments (IKEA)	NL	Recycling companies

#	Company	Location	Segment
76	D&E Entsorgung	DE	Recycling companies
77	Recticel	NL	Processing companies/ foamers
78	VitaGroup	UK	Processing companies/ foamers
79	FederalEcoFoam	NL	Processing companies/ foamers
80	Confidential	EU	Others
81	Independent consultant	EU	Others
82	Matratzenverband	DE	Others
83	Independent consultant	EU	Others
84	Independent consultant	EU	Others
85	Independent consultant	EU	Others

PIW vs. PCW – price history & potential drivers

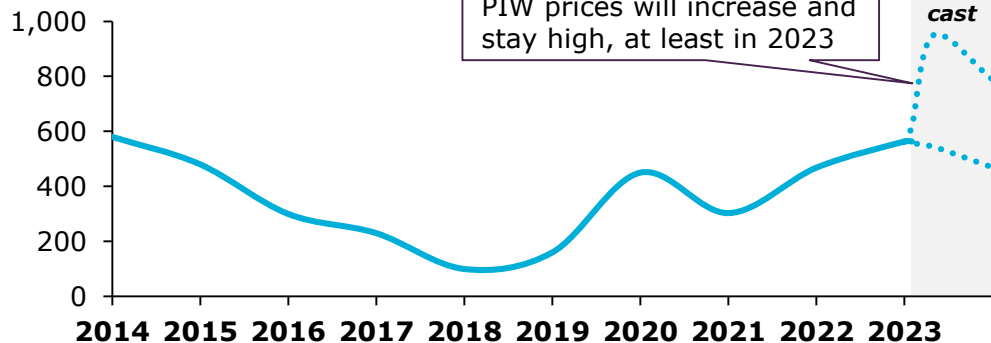
Pre-read

Prices for PU PIW has been subject to changes in the last years and expected to follow the trend of other polymers, e.g. PET.

Prices for PU PIW fluctuated strongly over the course of the last years and are expected to come back to an elevated baseline in 2023 and 2024

European price

in EUR/t



Price drivers:

- Export of trim foam (e.g. to MEA & North America)
- PU over/undersupply
- Increasing rebonded foam demand

Voice of the market

Prices for PIW fluctuate strongly over the last years.
- Federal EcoFoam

Prices for PIW doubled in 2023.
- Mechanical recycler

We increased the prices for our products three times now and did not lose a single customer.
- PU recycler

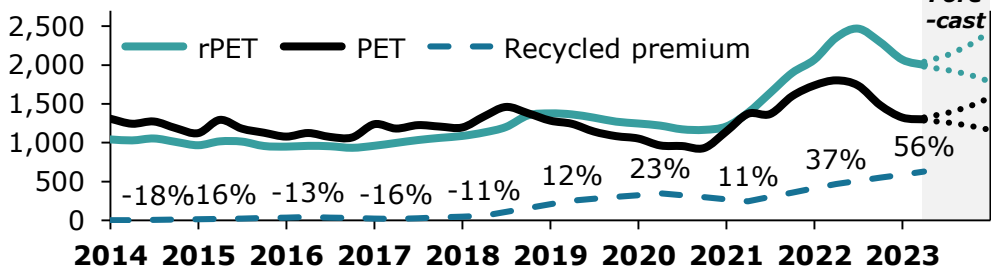
Strategic implications:

- It is assumed that **PU** will follow the path of other polymers (e.g. **PET**) that are further ahead in terms of circularity with a **time lag of a few years**.
- Decoupling** of recycled and virgin prices expected with an **increasing premium for rPolyol and rTDI**.
- Increasing prices** will drive needed **EoL infrastructure investments**.

Prices and premiums for recycled PET increased over the last years, driven by demand for recyclates and improved recycling infrastructure

European spot price

in EUR/t



Price drivers:

- Strong increase in recyclate demand (e.g. PET-based fibers in automotive)
- Limited supply of recyclate

Voice of the market

PU will go the route of similar products before and experience the same market dynamics.
- Foamer

A high recyclate price is not automatically good to push a circular solution of PU.
- Vita Group

Resulting outlook for 2028

Value chain will create high recycle demand

Increasing demand for recyclates drives prices

rTDI prices expected to see strong price increase over the next years

rPolyol prices expected to increase less than TDI due to higher output compared¹

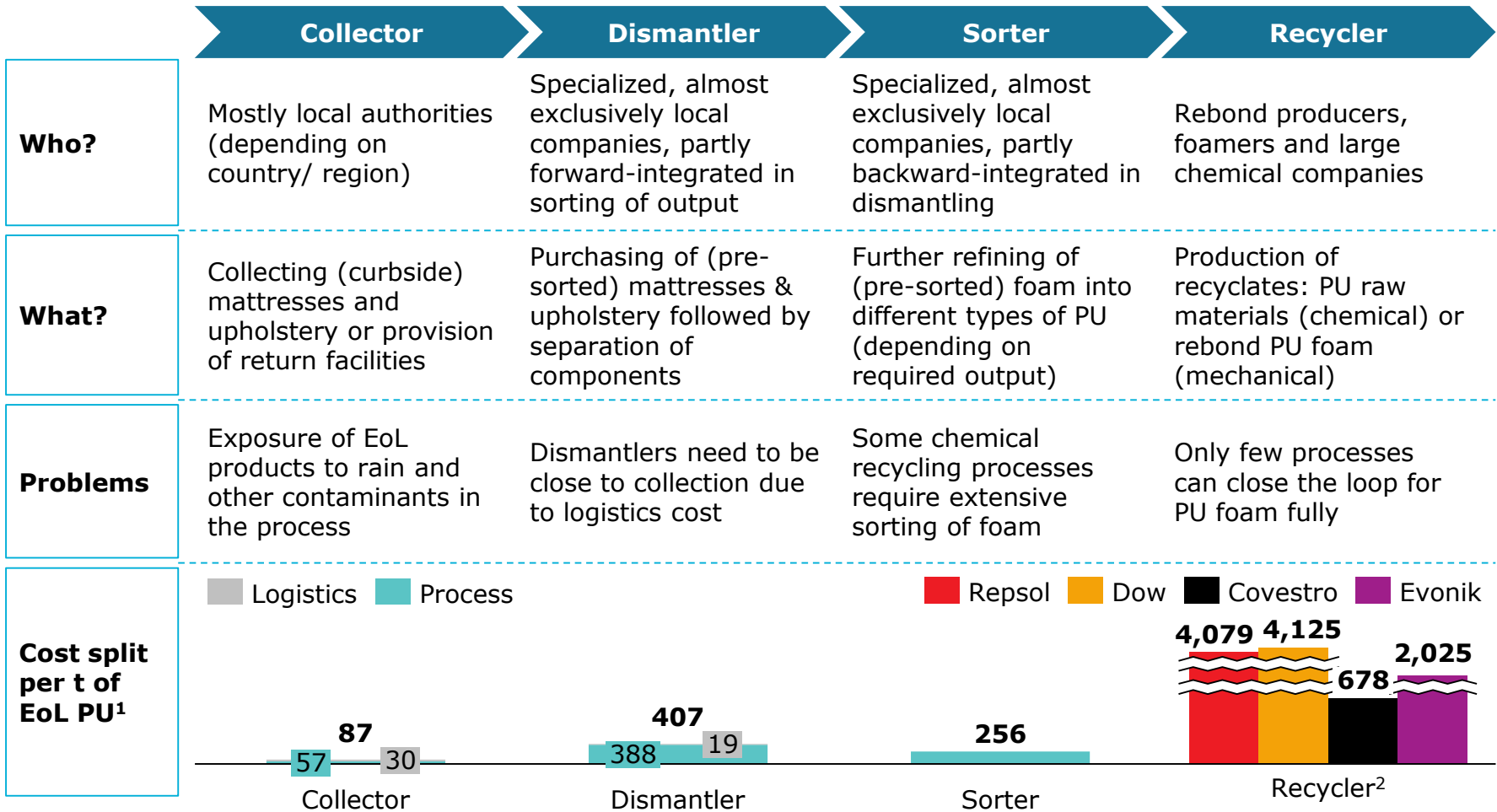
1. Based on the fact that all chemical recycling processes (incl. Dow & Repsol) yield Polyols, but only Evonik and Covestro produce recycled TDI

Sources: desk research, interviews, analysis & SuP expertise, PIW cost by Europur, PET spot prices by KI-web; PIW: Post industrial waste/by-product; PCW: Post consumer waste

EoL PU value chain overview

Pre-read

The value chain of EoL PU consists of various specialized actors that need to closely work together to fully close the loop for PU at acceptable cost.



Existing examples:

- Countries with **existing EPR** scheme (e.g. France & Netherlands) **made EoL PU dismantling and sorting profitable.**
- This created an **ecosystem** and **increased the available input** for recycling companies.

Strategic implications:

- **High degree of collaboration** and (partial) integration needed
- **Up front invest needs to be covered by regulatory security and incentives** (e.g. through EPR scheme).
- **Hub & spoke model needed to keep logistic costs down.**

1. All cost without EPR scheme

2. Repsol/Dow appear to be much more expensive at this point. This is because cost are only related to EoL foam entering the process. The product mass of these processes is however much higher compared to Covestro/Evonik, leading to lower overall cost in relation to rProduct obtained as shown within this study.

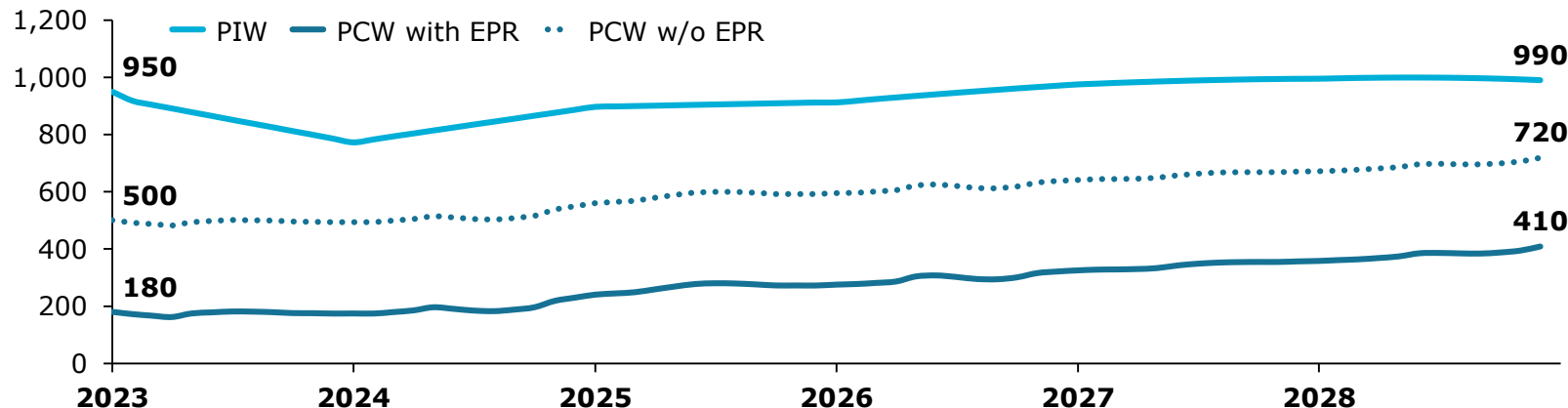
Sources: desk research, interviews, analysis & SuP expertise; EoL: End of life; EPR: Extended producer responsibility

PIW vs. PCW – price forecast – scenario 1

With or without EPR scheme the European prices for PIW and PCW are expected to see a above average increase until 2028, driven by increasing demand for recyclates.

Scenario 1

Forecast based on cyclical pricing of PIW and an assumed medium price premium, especially for high quality PCW in EUR/t



Price drivers for PIW:

- Slightly higher demand for mechanical recycling.
- Stable overseas exports will keep prices flat.
- This leads to a similar growth rate compared to PCW.

Price drivers for PCW:

- Stable and slightly increasing demand for mechanical & chemical recycling.
- Average EPR amount expected to slightly decrease from 2026 onwards as infrastructure buildup gains momentum.

A 2.5% annual reduction of carbon footprint is sufficient to reach the Paris Agreement. (...) using PIW is a first step as it is much cheaper than virgin material.

- VITA Group

With good infrastructure the PCW demand will increase over the next years and so will the prices, keeping PIW attractive.

- Mechanical recycler

Strategic implications:

- With or without the effect of EPR, prices for PCW is expected to be lower than PIW in 2028.
- However, the difference is expected to decrease over time due to the increasing demand for high quality PCW from EoL PU driving the recycled premium price.
- Long term price development highly dependent on PCW vs. PIW demand and the ability of the recycling infrastructure to keep up with the respective output.
- Amount of EPR driving prices for PCW through increasing of available output.



Resulting price outlook for 2028



990 EUR/t For PIW



720 EUR/t For PCW if no EPR is applied



410 EUR/t For PCW if EPR is applied

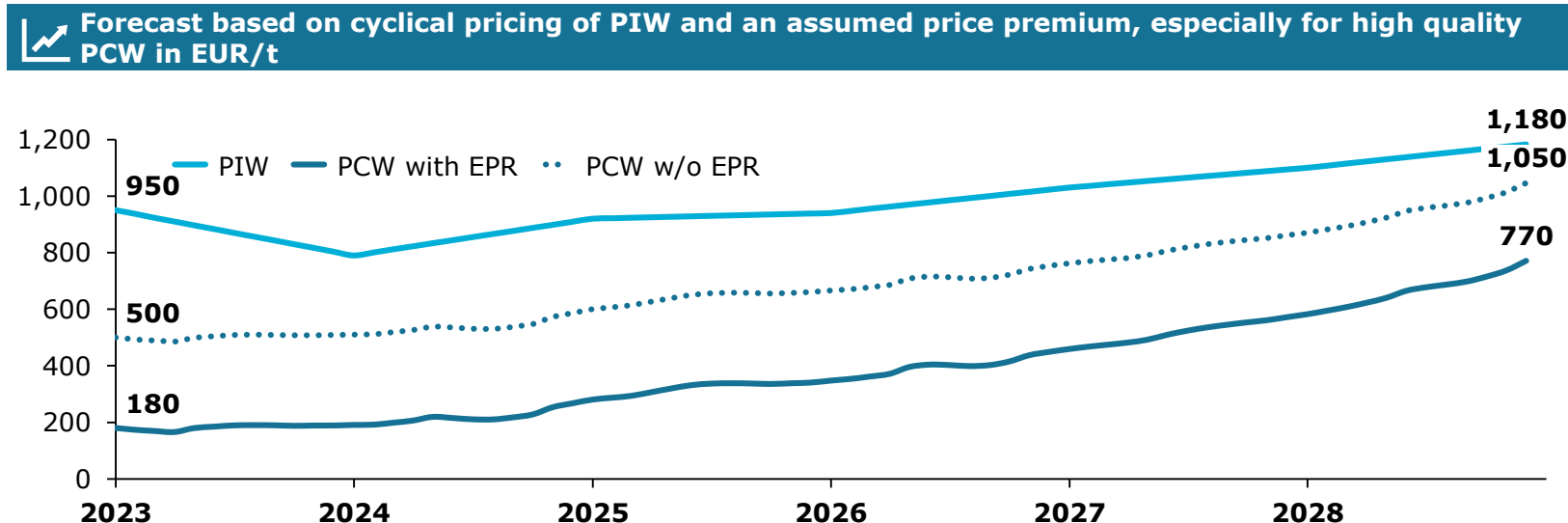
Sources: desk research, interviews, analysis & SuP expertise; EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste; EPR: Extended producer responsibility

PIW vs. PCW – price forecast – scenario 2

Pre-read

With or without EPR scheme the European prices for PIW and PCW are expected to see a strong increase until 2028, driven by higher demand for recyclates.

Scenario 2



Price drivers for PIW:

- **Higher demand for mechanical recycling.**
- **Decreasing oversea exports** on the other side will lead to an oversupply of PIW.
- **This leads to a lower growth rate compared to PCW.**

Price drivers for PCW:

- **Higher demand for mechanical & chemical recycling.**
- **Average EPR** amount expected to **decrease from 2026 onwards** as infrastructure buildup gains momentum.

“ A 2.5% annual reduction of carbon footprint is sufficient to reach the Paris Agreement. (...) using PIW is a first step as it is much cheaper than virgin material. ”
- VITA Group

“ With good infrastructure the PCW demand will increase over the next years and so will the prices, keeping PIW attractive. ”
- Mechanical recycler

Strategic implications:

- **With or without** the effect of **EPR**, prices for **PCW** is expected to be **lower than PIW** in **2028**.
- However, the **difference is expected to decrease** over time due to the **increasing demand for high quality PCW** from EoL PU driving the recycled premium price.
- **Long term price development** highly dependent on **PCW vs. PIW demand** and the ability of the **recycling infrastructure to keep up with the respective output**.
- **Amount of EPR driving prices for PCW** through increasing of available output.

Resulting price outlook for 2028

1,180 EUR/t | For PIW

1,050 EUR/t | For PCW if no EPR is applied

770 EUR/t | For PCW if EPR is applied

Sources: desk research, interviews, analysis & SuP expertise; EoL: End of life; PIW: Post industrial waste/by-product; PCW: Post consumer waste; EPR: Extended producer responsibility

PIW vs. PCW – price forecast – assumptions

In order to model the future prices for PCW and PIW, SuP set up a pricing model taking into account historic price developments, future price premiums and economic influencing factors.

SuP approach for PCW/ PIW forecast model

- Generally, the cyclical nature of the PU market, but also the strong price fluctuations of PCW and PIW were analyzed in the past
- A price model was set up to combine this volatility with added linear growth in the future

Price forecast based on historic prices, incl. circularity

+

PIW/PCW price premium growth

+

Economic influencing factors

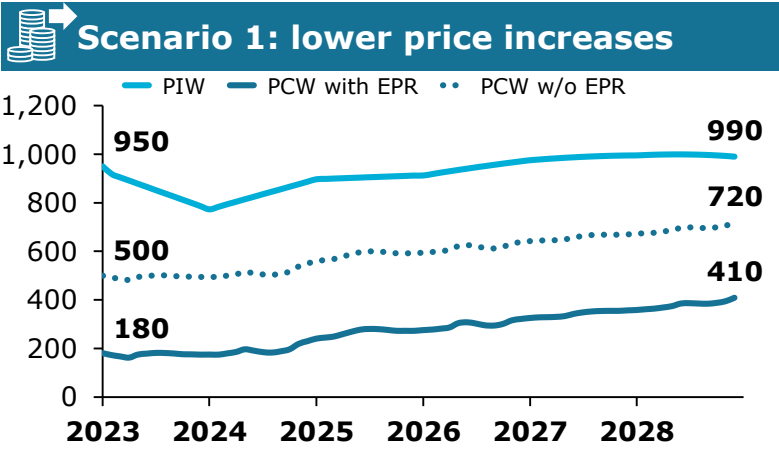
Total price growth

- PIW price premium growth p.a.
- PCW price premium p.a.
- EPR reduction p.a.

General drivers influencing the PIW price growth along the forecasted period

General drivers influencing the PCW price growth along the forecasted period

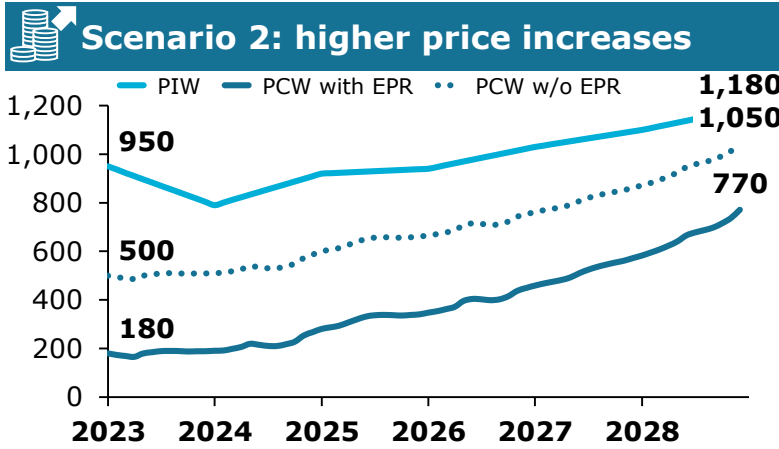
Sources: desk research, interviews, analysis & SuP expertise



-1%	0%
1%	1%
0%	1%

- Price drivers for PIW:
- Slightly higher demand for mechanical recycling.
 - Stabile oversea exports will keep prices flat.
 - This leads to a similar growth rate compared to PCW.

- Price drivers for PCW:
- Stabile and slightly increasing demand for mechanical & chemical recycling.



0%	1%
2%	2%
0%	5%

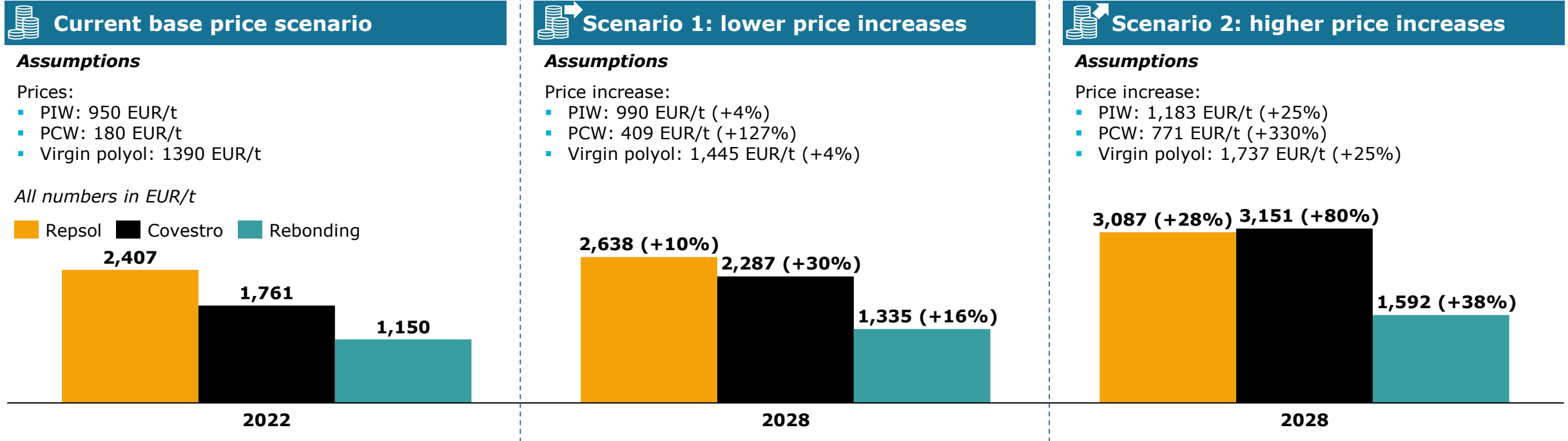
- Price drivers for PIW:
- Higher demand for mechanical recycling.
 - Decreasing oversea exports on the other side will lead to an oversupply of PIW.
 - This leads to a lower growth rate compared to PCW.

- Price drivers for PCW:
- Higher demand for mechanical & chemical recycling.

Price sensitivity

Pre-read

Covestro's process is affected most by increasing prices. The recycled product price increase is ~1/4 of the PCW price increase.



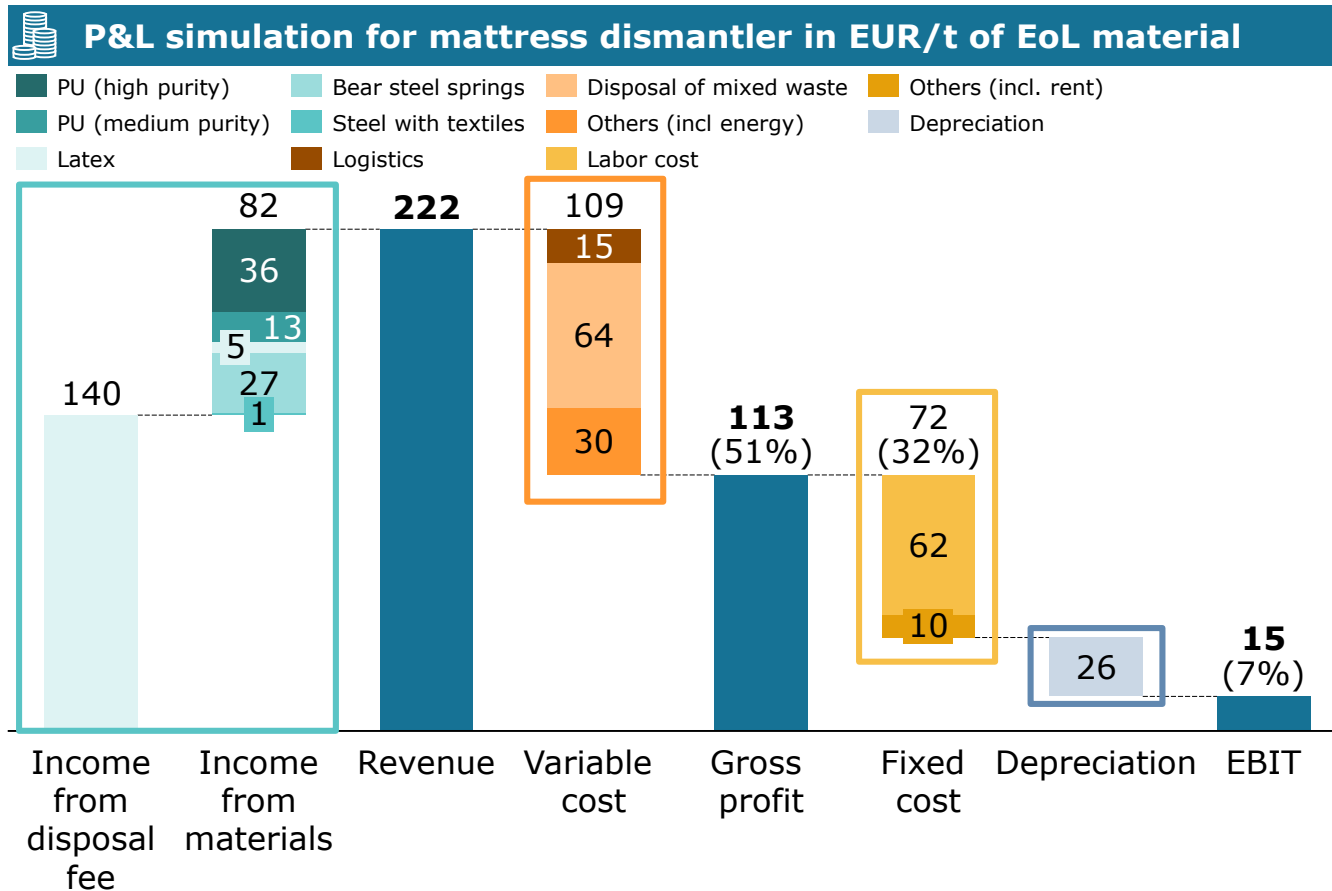
- **Covestro's recycled product price increases drastically** with increasing PCW prices. This is due to their higher purity needs and associated to that higher demand for end of life foam.
- **Repsol's** product price is affected both by increasing **PCW as well as virgin** polyol prices. As the **share of pre-treatment cost is lower** compared to the Covestro process, the resulting price increase becomes lower.
- As **both PIW and PCW can be used as feedstock for rebonded foam**, the price development is a mean of both price increases.

Sources: desk research, interviews, analysis & SuP expertise, PCW: Post consumer waste

Dismantling cost model for a Germany-based player

Pre-read

Based on interviews, published company financial as well as data modelling a German based dismantler is barely profitable without an EPR scheme.



Income details

- The income from disposal equals the amount a collector & sorting is willing to pay to get the mattress disposed and includes the logistics cost, which is usually low due to proximity of dismantler and collector.
- Competing incineration cost expected to be around 150 EUR per ton.

Variable cost details

- Logistics highly dependent on distances the EoL materials have to travel due to their low density.
- For this case a distance of less than 100 km is assumed.

Fixed cost details

- Labor cost determined by local minimum wage.

Depreciation details

- Initial invest estimated at 5 M EUR for a 10 -15 kt plant.

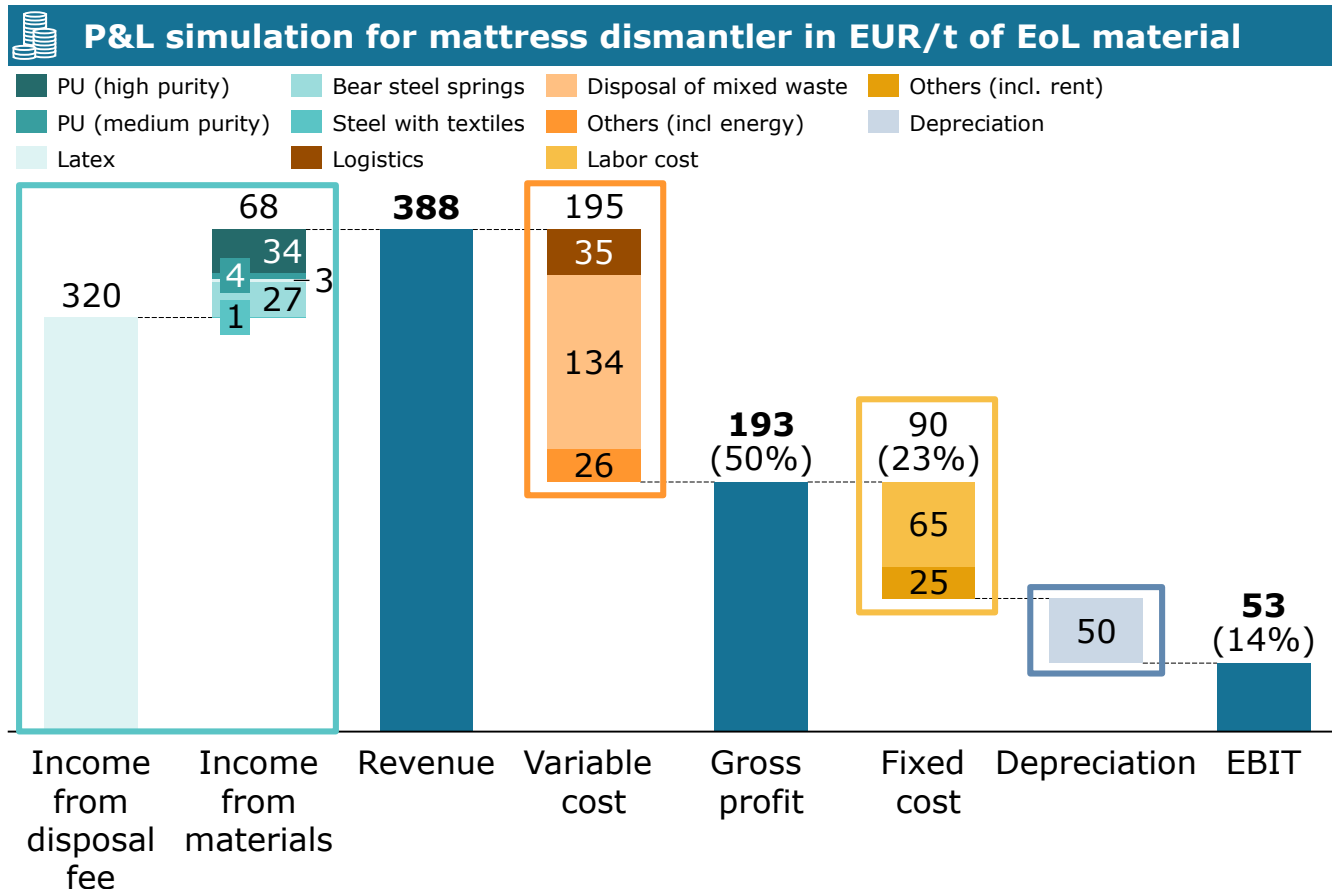
Currently no EPR scheme in place and existing dismantler barely profitable (only through low logistics cost).

Sources: SuP desk research, interviews & analysis; financial reports of dismantlers

Dismantling cost model for a Belgium/Netherlands-based player

Pre-read

Based on interviews, published company financial as well as data modelling a dismantler based in Belgium or the Netherlands is profitable due to an EPR scheme.



Income details

- The income from disposal equals the amount a collector & sorting is willing to pay to get the mattress disposed and includes the logistics cost, which is usually low due to proximity of dismantler and collector.

Variable cost details

- Logistics highly dependent on distances the EoL materials have to travel due to their low density.
- For this case a distance of less than 100 km is assumed, yet interviews with Dutch players indicate, that the process is still profitable at distance up to 300 km.

Fixed cost details

- Labor cost determined by local minimum wage.

Depreciation details

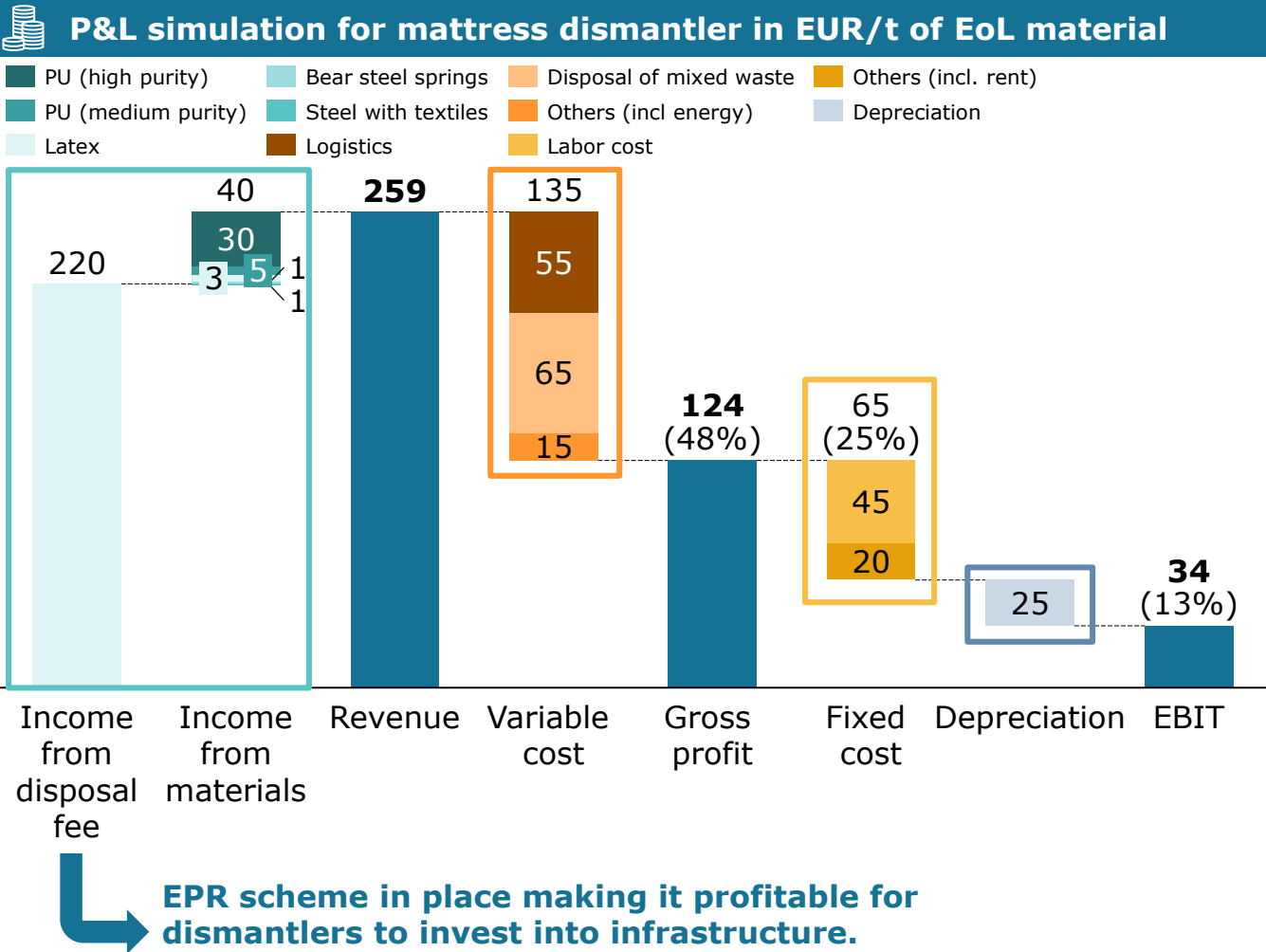
- Initial invest estimated at 5 M EUR for a 10 -15 kt plant.

EPR scheme in place making it profitable for dismantlers to invest into infrastructure.

Sources: SuP desk research, interviews & analysis; financial reports of dismantlers

Dismantling cost model for a France-based player

Based on interviews, published company financial as well as data modelling a dismantler based in France is profitable due to an EPR scheme.



Income details

- The income from disposal equals the amount a collector & sorting is willing to pay to get the mattress disposed and includes the logistics cost, which is usually low due to proximity of dismantler and collector.

Variable cost details

- Logistics highly dependent on distances the EoL materials have to travel due to their low density.
- For this case a distance of less than 300 km is assumed.

Fixed cost details

- Labor cost determined by local minimum wage.
- Lower energy but higher logistics cost compared to the other countries due to lower population density.

Depreciation details

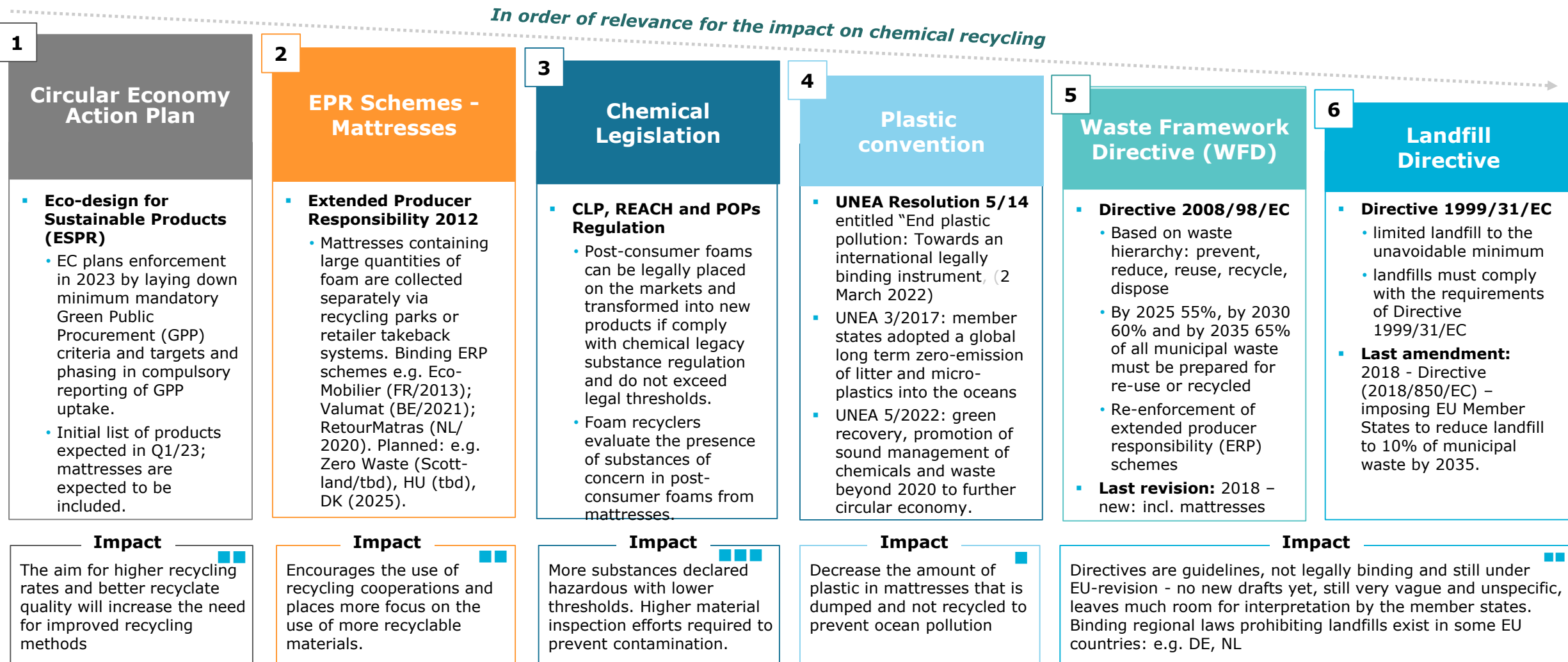
- Initial invest estimated at 4 M EUR for a 10 -15 kt plant.

Sources: SuP desk research, interviews & analysis; financial reports of dismantlers

Legal Regulatory Environment: End of life

Pre-read

The current objective for all legislation covering waste is to reduce incineration and landfilling while favoring the conservation of resources via re-use or recycling.



Sources: SuP interviews and desk research

■■■ immediate ■■ 5-10 years ■ 10 years +

Insights suggest that mattresses have moved much more in the focus of legislation when it comes to their EoL disposal.



The most **important directive is the Waste Framework Directive (WFD)**. New regulations are in the pipeline. Very important to watch is the new **Ecodesign for Sustainable Products (ESPR)**. It is new now and still very vague, but that will change in the future. It **will become mandatory very soon**. Producers will be required to prove the amount of green and recycled content of a product they produce and sell.

Association, Belgium



Another law that will effect the foam for mattresses and will become more important is the **Chemical Directive which lists the forbidden substances for recycling**. This regulation is still in the process and keeps changing - is in an ongoing process when it comes to relevant chemical legacy substances.

Association, Belgium



The EU **directives are only guidelines and not binding**. The provide a much room for interpretation by the EU member states

Chemical company, Germany



The **landfill directive** is not relevant for PU foam producers but for the **mattress producers**. There is a clear target that by 2035 all EU Member States are required to **reduce landfill waste to 10%** or even less of municipal waste.

The Extended Producer Responsibility (**ERP schemes**) is, so far, not **binding** across the whole of Europe, only **in Belgium, Netherlands and France**.

Association, Belgium



The **classification of mattresses as bulky waste** will, following indications from the Ministry of Economics and the Ministry of the Environment, be **changed** as part of the revision of the "**Blauer Engel** Mattresses". This will increase the urgency

Association, Germany



In Germany, **dumping mattresses in landfills has been prohibited legally since 2006**. It is fined. In the UK it is dealt with by higher taxation according to disposal form. Landfill is more expensive, as far as I know.

Authority, Germany

Disposal chain and cost of EoL mattresses: key trends and challenges

Increasing responsibility is given to the producers, when it comes to EoL mattresses. So far, producers mainly take over voluntary responsibility, which is not yet binding.

Key drivers for an improved EoL mattress disposal process



Design to recycle

- Producers work on designs that are easier to take apart; e.g. reducing glue and different foam types or also re



Relevance for the client



Recycled content

- Governments are working hard on increasing the compulsory share of recycled and green materials in mattresses.



Relevance for the client



EPR schemes

- Voluntary initiative (NL) from the producers for encouraging its recycling.
- France has a compulsory EPR paying scheme in place



Relevance for the client



Capacity expansion

- In the EU a massive expansion of recycling capacity is taking place
- Government and industry funded projects are underway.



Relevance for the client



Limited re-usability

Limited reuse of mattresses due to consumer and industry concerns regarding hygiene and cleanliness. Especially in care homes and hospitals regulations are very strict.



Relevance for the client



Government involvement

- Official entities supervise entire value chain (e.g. FR)
- Municipal bulky waste collection creates minimum effort for individuals to dispose of EoL mattresses



Relevance for the client



In the Netherlands, the **system works better without a mandatory EPR than in France**. What needs to be improved is the retour flow to the producers and retailers – but so many offer a **sleep guarantee**, so consumers **don't want to have the old mattress picked up** before they do not know that the new one works. Also with the roll-up mattresses they need 1-3 days to get into shape.

Retailer, Netherlands

■■■ high ■■ medium ■ low

Sources: SuP desk research and interviews

Disposal chain and cost of EoL mattresses: key trends and challenges

Pre-read

One of the main retarders when it comes to chemical recycling is the waste stream which is dealt with on a very regional level. Few mattresses are returned to the producers.

Key retarders/challenges for the EoL mattress disposal process



Lack of infrastructure

There is a lack of national infrastructure in the waste stream in most EU countries. Most waste disposal is handled at a very regional level and not moved further.



Relevance for the client



Outside disposal

Outside the waste stream ways disposal still prevalent in many EU countries and increased in the EU during Covid-19 and the continuing energy crisis.



Relevance for the client



Lack of awareness

Sales and customer service know very little about retour and take back schemes, especially where mattress go from there and thus do not encourage it.



Relevance for the client



Recycling limitations

Quality of EoL mattresses, clean separateability of materials are challenging to recycling, e.g. glue, fire retardants, types of foam and additives



Relevance for the client



Stakeholder interests

Differing political, technical and commercial stakeholder interests slow the process, create inflexibility in the decision making for effective policy measures.



Relevance for the client



Hard to handle

EoL mattresses are bulky, have a large volume, are difficult to compact and transport. They are a challenge for the whole waste stream.



Relevance for the client



Take back schemes

- Retailer 'take back schemes' are more frequently used than producer schemes. Many EoL mattresses never reach producer recyclers.



Relevance for the client



Increase re-usability

- Producers use eco-friendly designs to make mattresses reusable, that could be leased to consumers for a time period, then stripped and refreshed.



Relevance for the client



Sources: SuP desk research and interviews

■■■ high ■■ medium ■ low

While only the few countries have introduced EPR schemes, many producers in other countries are also working on new concepts to reduce the waste produced by EoL mattresses.

//

We do not have an EoL concept yet, but we take a lot of responsibility with the production of our mattresses. We have an **extended lifespan** with a guarantee of 10 years due to the heavy latex foam, we use. All our mattresses are bio-degradable as we only use **GOTS certified natural latex** and cotton. We do not take old mattresses back at the EoL, but we do take the **retour mattresses** back within the first 100 days. We clean them and **sell them on ebay**.

Brand owner, Germany

//

We already produce long lasting mattresses. While normal mattresses last 5-7 years ours **last 10-12 years**. That already is reducing the amount of waste produced by us by 50%. For some of our foams we use **natural rubber which is bio-degradable**. Also, we are in the process to developing two new mattress types: one, which is **foam-free** consisting of a pocket spring core and various nonwoven materials. The other consists to **100% of one material**. This makes it much easier to recycle.

Brand owner, Germany

//

All our **mattresses can be returned to us**. We also pick up mattresses from other brands if you buy one from us. We introduced three new types of mattresses. **Two of them are 100% circular** and we make new mattresses out of them and one type is 80% circular. The 100% were introduced in 2020. As they are quite new the customers have to first get used to them and learn more about them. But the sales is developing well. **Their price is the same as the other mattresses**. All of the materials in those three mattress types can be **recycled into a new mattress over and over again**. They are made of steel and polyester only. With a new concept the adhesive can even be separated from the layers of the mattress. Our goal is not to have our mattresses end up in landfill nor being burnt. So we want to **reclaim our mattresses to make new ones** of them.

Brand owner, Netherlands

The sales personal the retailers are often not aware of what happens to the old mattresses and in Germany sales reps often discourage customers to use their EoL take back service.

// **Old foam cannot be reused for mattresses.** The tension is gone. It can be used for pillows or toppers. *Retailer, Germany*

I always **discourage** my **customers from using our service to get rid off their old mattress**, but give it to the council recycling center as it is much cheaper. *Retail chain, Germany*

// We have a recycling program in place. Your **old mattress is picked up for 35 pounds** and taken to a recycling center which we cooperate with. It is dismantled and made into something new. However, very rarely customers here ask for what happened with the mattress when it is picked up. We encourage people to give the still-in-good-shape old mattress to a **charity program we work with**. The local council picks up old mattresses cheaper, but there you do not know what happens with it. So **we discourage people from doing that and sell or donate to friends and relatives**. We also have a product line which is called 'Slumberland', where old PET bottles are processed for making the mattress. The mattresses are not cheaper. *Retailer, UK*

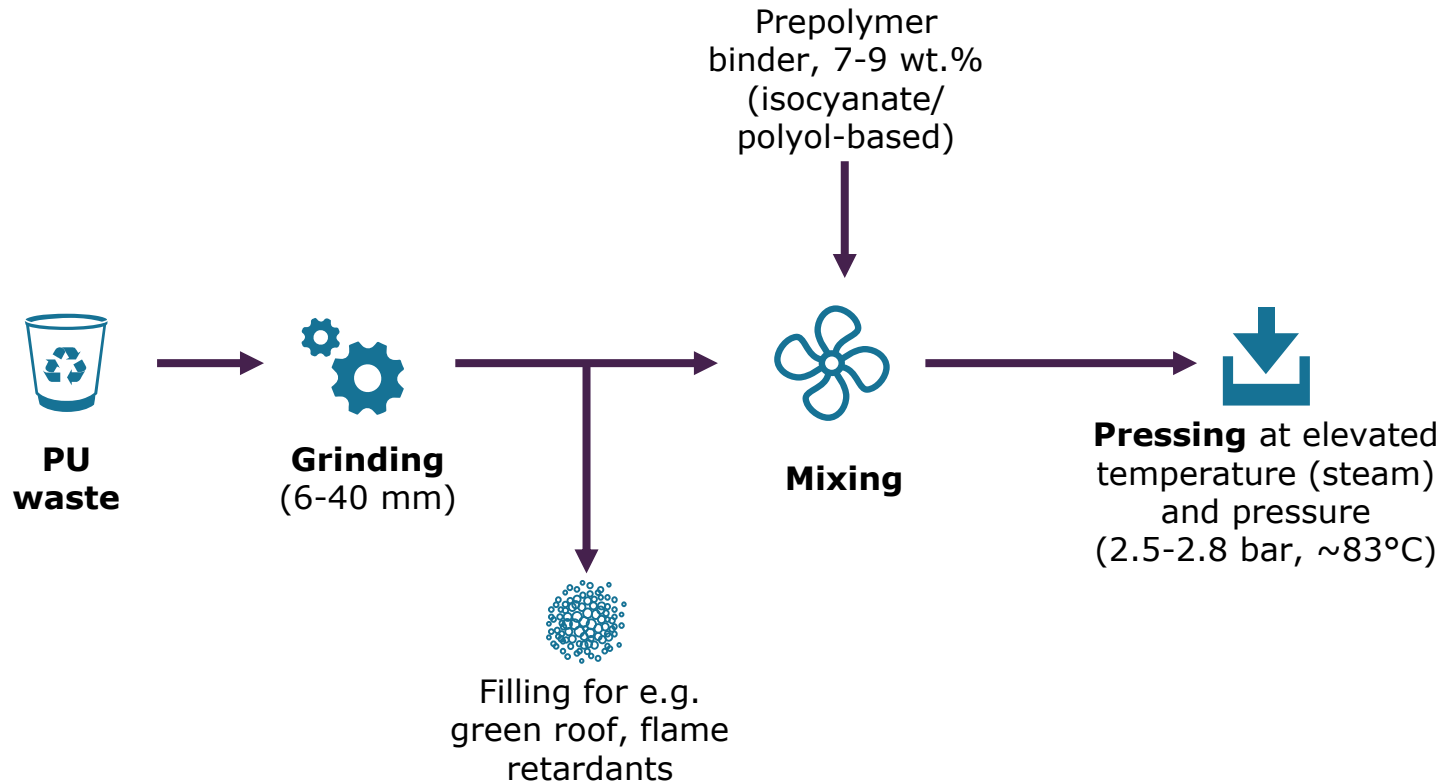
// We still have to deal with the **old mattresses we take back from customers ourselves**. We have a big container here from the city government. What they do with it, I don't know. We are still not allowed to give old, still usable mattresses to refugees or homeless homes. What happens increasingly is, that **customers give their old mattresses to neighbors, relatives etc. and we help them transporting it there**, when we deliver the new mattress. We also take new mattresses back within the first three weeks and **clean the covers in big washing machines and resell them in the upper floor of our shops cheaper**. Old foam cannot be reused for mattresses. The tension is gone. It can be used for pillows and other *Retailer, Germany*

// We have had **Second Life mattresses program** for quite some time. Because we sell these mattresses for **50% of the original price they are very popular**. We even offer for all our Second Life mattresses a full 10-year warranty on the durability of materials and the mattress core. The returned products are, after careful examination, professionally refurbished, the cover is replaced and the foam **undergoes UV light decontamination**. These are therefore refurbished products according to certified and high quality standards. *Online Brandowner/Retailer, Germany*

Mechanical recycling process

Pre-read

Rebonding is the dominant technology used today for the recycling of PU foams. It includes downcycling for use in e.g. flooring or carpet underlays.



- **Post industrial waste** is the most important input material. **Post consumer waste** was only barely used in the past, but growing in relevance.
- If pure PU foam is to be rebound, the share of binder necessary usually values around 7-9 wt.%. If inorganic fillers like silica or talc are added for improved softness or plushness, the value can increase to ~35% depending on the filler content.
- Alternatively to rebonding, ground PU waste can also be reused as filler in the production of new foams. The grinding effort increases significantly as particle sizes of ~250 µm are required.
- Another possibility is the avoidance of binder by compression of the foam waste at high temperature and higher pressure of ~350 bar.

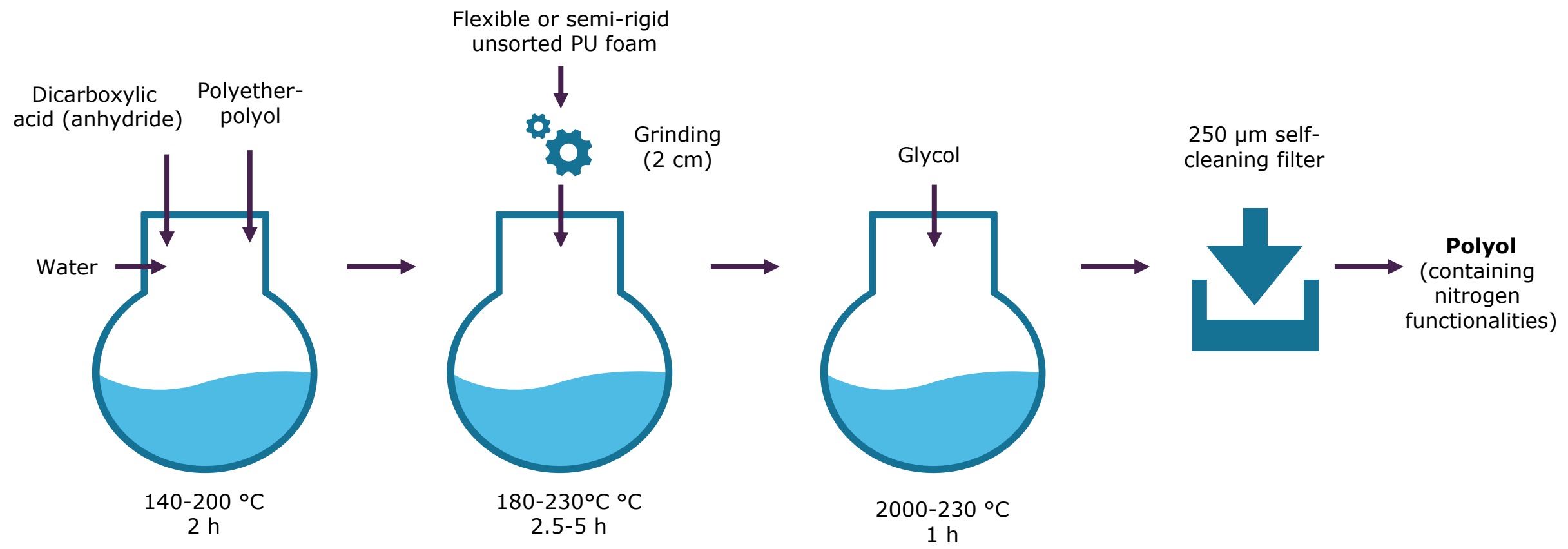
Sources: Interviews, desk research & patent analysis; US5290818; US6136870; US9410026B1

PU recycling process deep dive – Dow

Pre-read

Dow's process developed with H&S Anlagentechnik is based on a combination of acidolysis and glycolysis. The rPolyol is most suitable for use in rigid foam.

Dow process



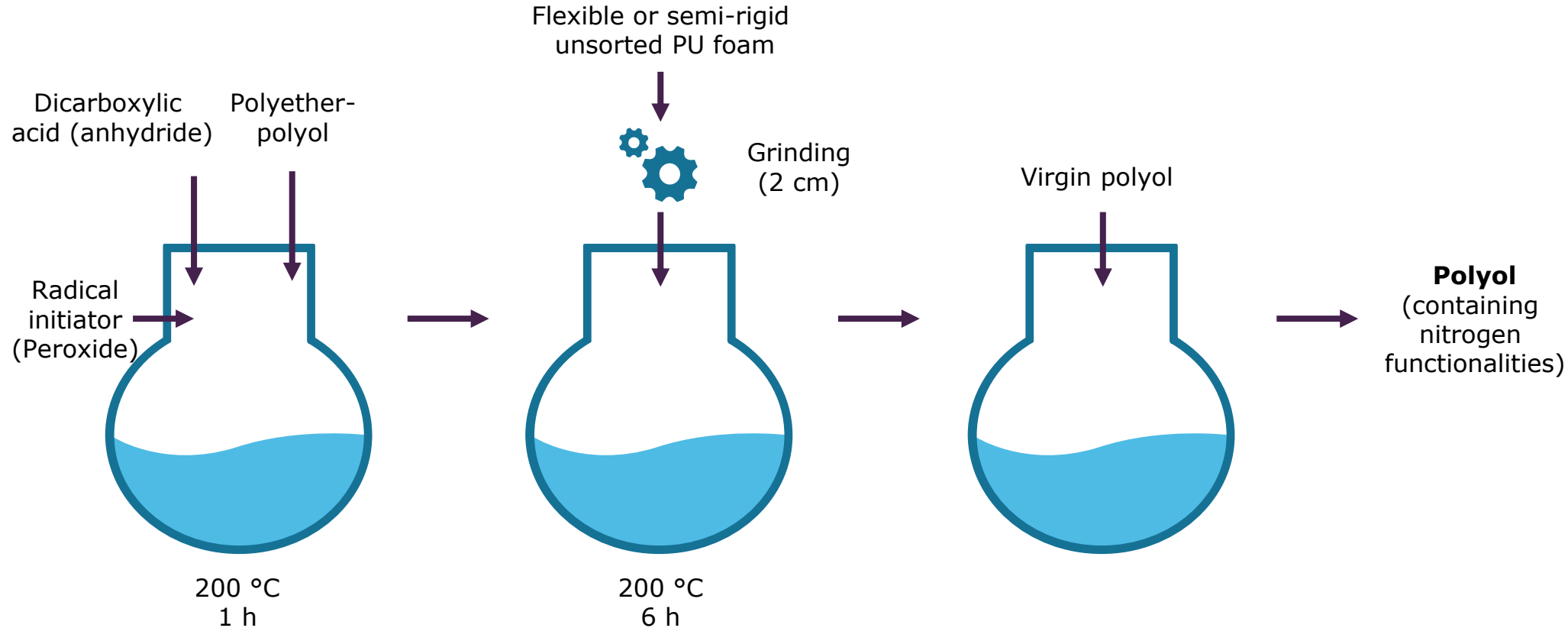
Sources: Interviews, desk research & patent analysis; DE102016122275A1; WO2022074184A1

PU recycling process deep dive – Repsol

Pre-read

The Repsol process with Rampf technology is very similar to the Dow/H&S process and differs only in detail. Up to ~20% virgin polyol can be replaced.

Repsol process



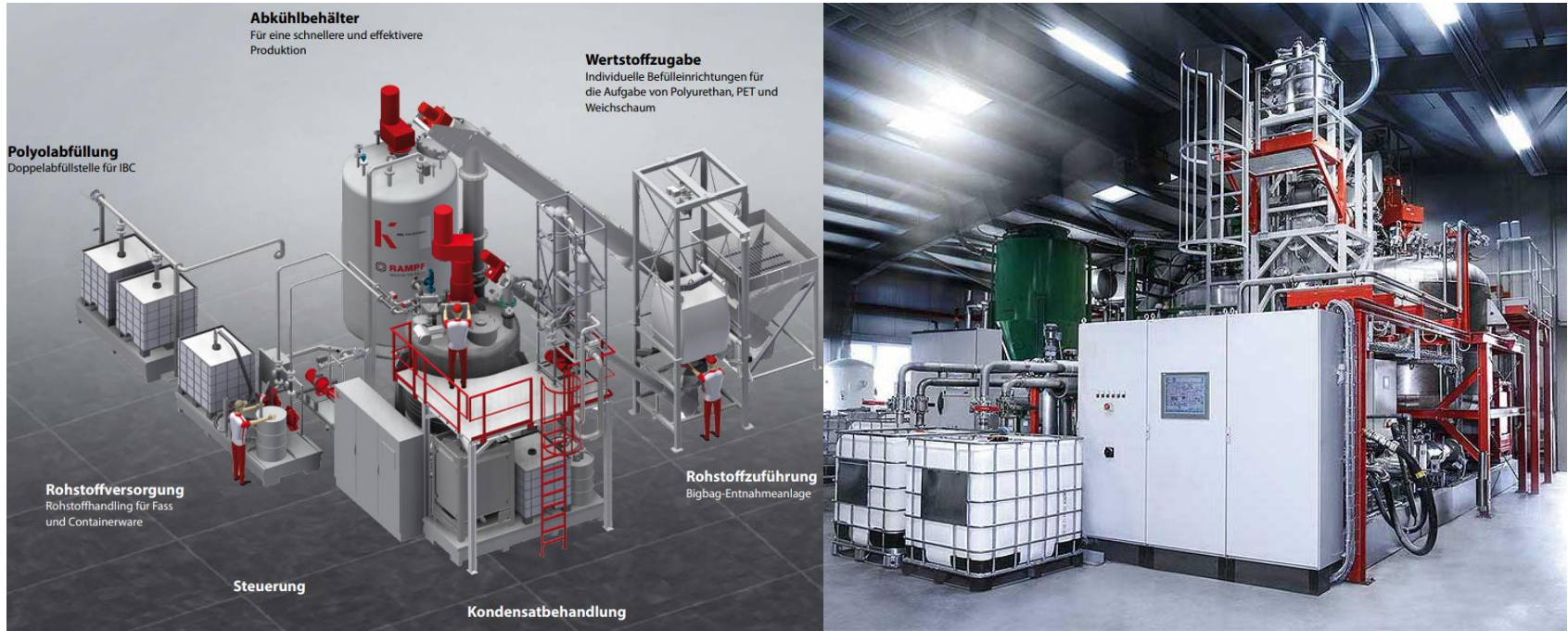
Sources: DE102013106364A1, DE19512778C1

PU recycling process deep dive – Repsol insights via Rampf process details

Pre-read

The Repsol recycling process is based on engineering work of RAMPF Eco Solutions & KEIL Anlagenbau, both based in Germany.

Repsol process



		Reactor BG 5	Reactor BG 7	Reactor BG 10
Reactor content	[Liter]	7,000	10,000	14,000
Batchsize	[kg]	5,000	7,000	10,000
Output 1	[kg/24h]	12,000	14,000	18,500
Output 2	[kg/24h]	7,300	7,800	9,600
Input	[kg/batch]	up to 2,000	up to 2,800	up to 4,000
Heating power	[kW]	500	500	650
Cooling power	[kW]	500	750	1,000
Content	[Liter]	5,000	7,000	10,000

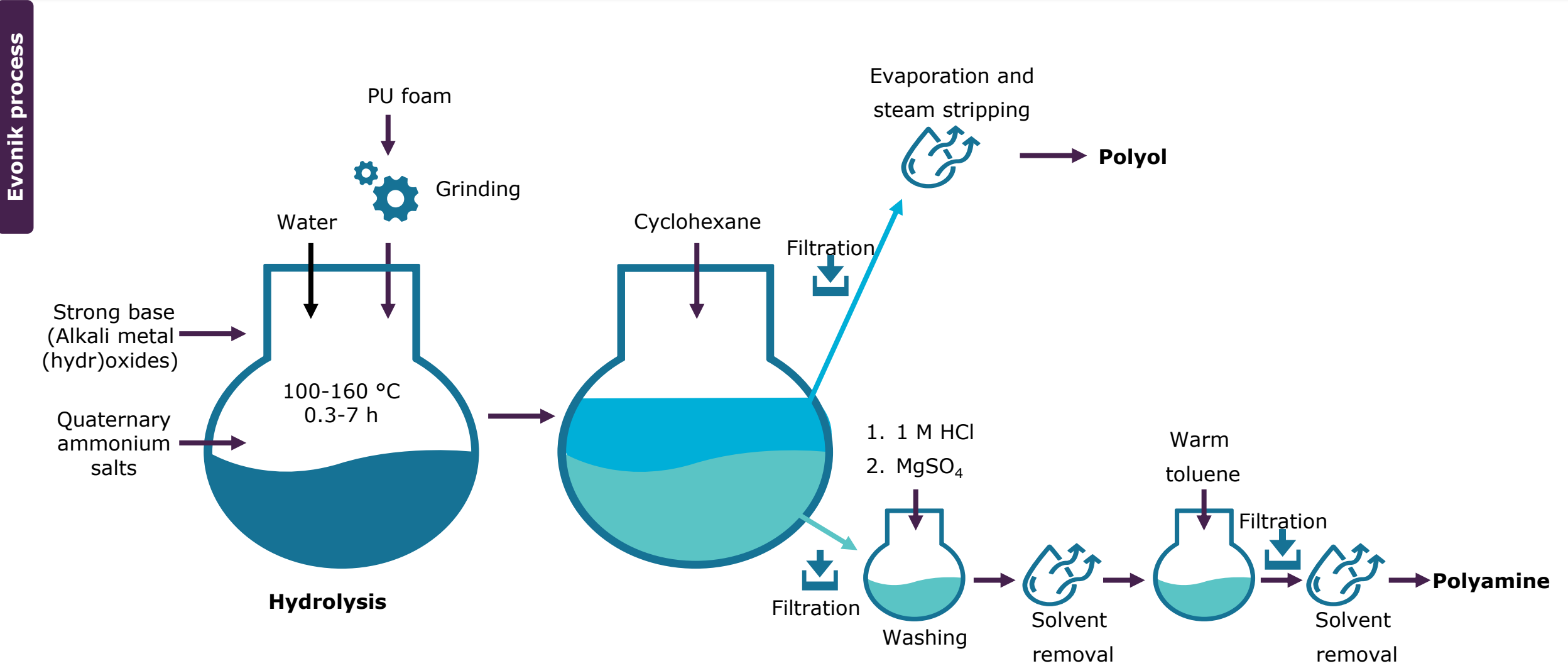
- **Engineering of plant done by cooperation of RAMPF Eco Solutions & KEIL Anlagenbau**
- **Peripheral equipment:**
 - Tank systems for the storage of raw materials and finished goods
 - Individual storage concept
 - Heat transfer oil supply systems & refrigeration plants
 - Individual design and supply of energy supply
 - Compressed air and nitrogen generation systems
 - Raw and recyclable material conveying systems
 - Customized feeding systems for raw and valuable materials

Sources: Patents

PU recycling process deep dive – Evonik

Pre-read

Evonik claims to be able to recover polyols as well as amines in a quality to replace 100% of virgin material by hydrolysis.

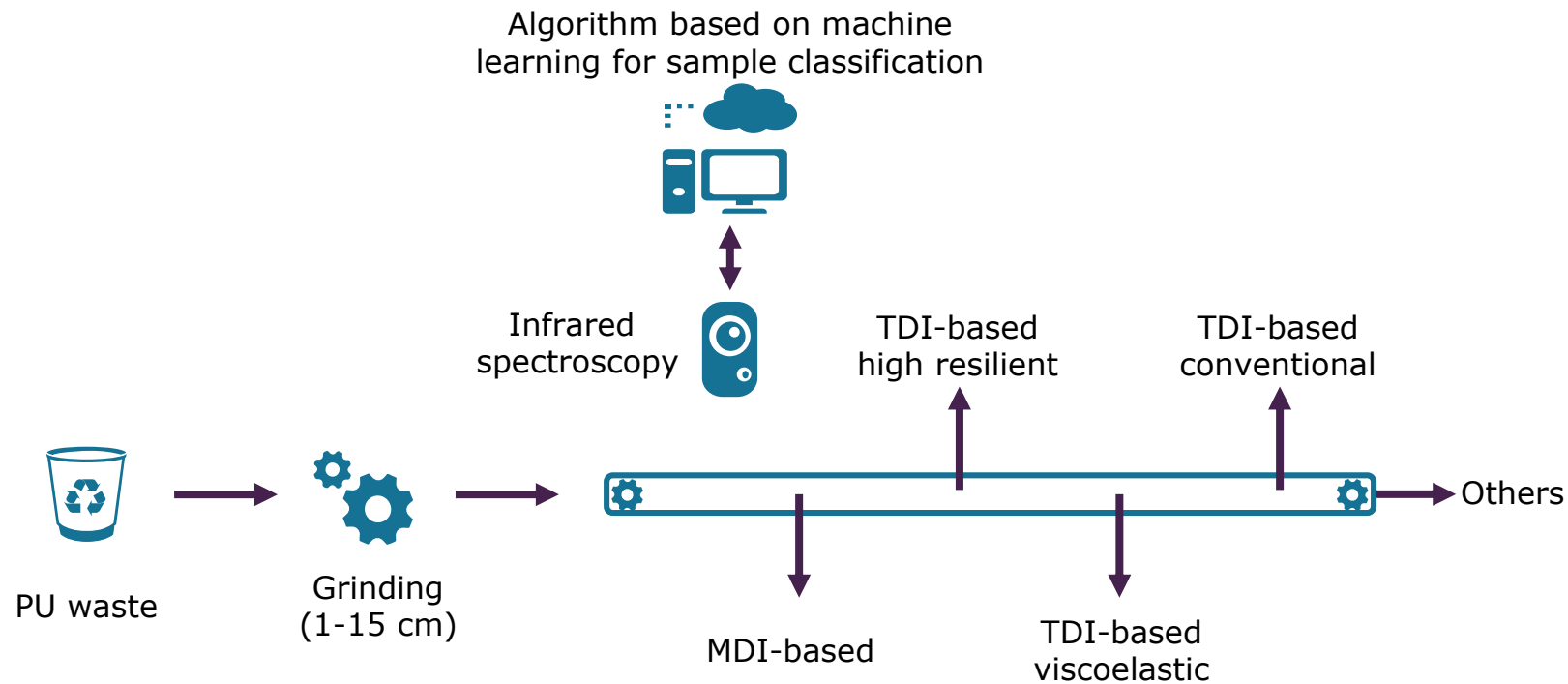


Sources: Interviews, desk research & patent analysis; WO2022042910A1

PU recycling process deep dive – Covestro – sorting overview

Pre-read

Covestro utilizes NIR in order to sort the foam waste into different fractions based on the type of PU used for its synthesis.



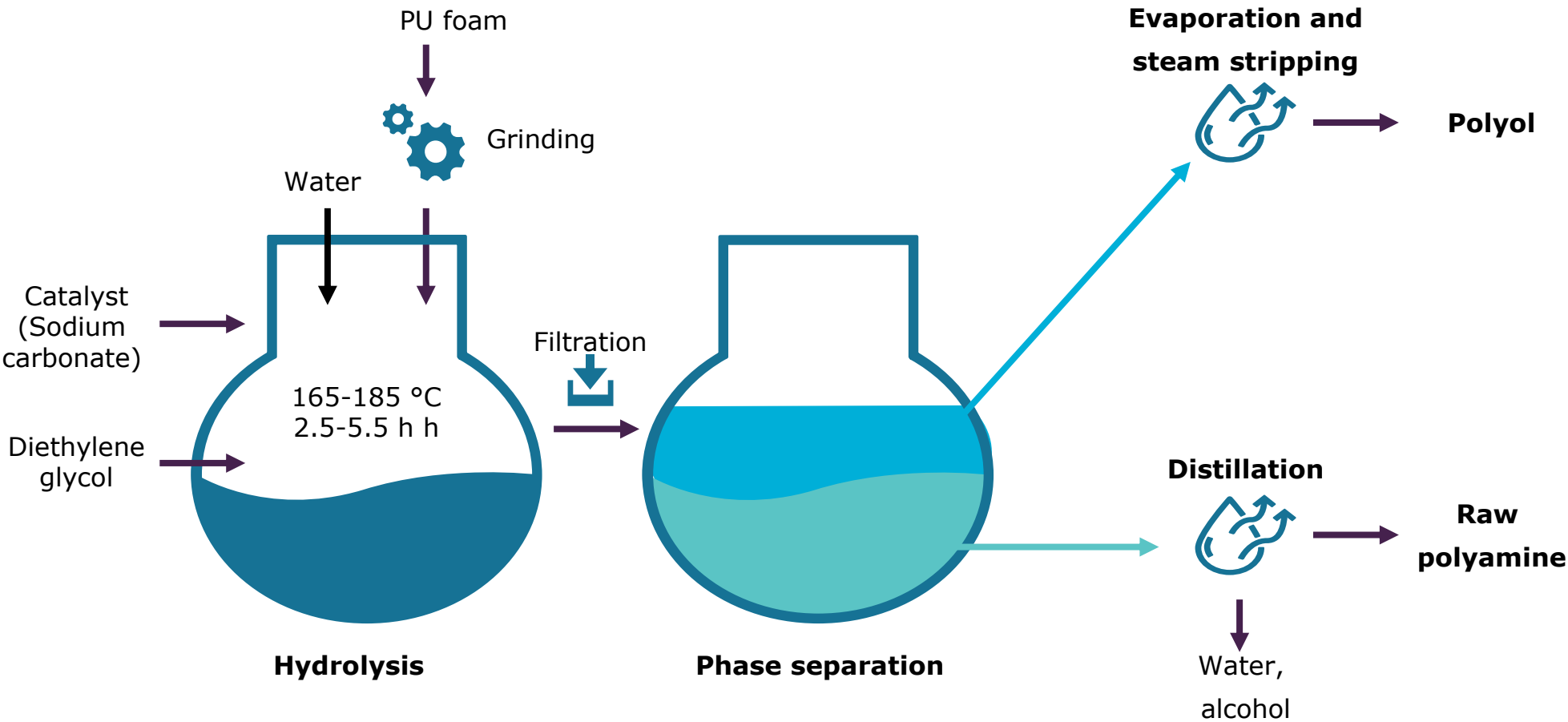
- The **automatic sorting** process is based on an algorithm capable of **supervised learning**.
- Samples are compared to **reference spectra** and separated according to their chemical structure.
- **Contaminations** such as paper, textiles or other polymers can be recognized as well.
- **TDI can further be separated** according to the proportion of 2,4- to 2,6 toluene diisocyanate.
- Polyol types are separated according to their **OH number**.
- Further classifications based on ingredients like toxic additives or flame retardants are possible as well.

Sources: Interviews, desk research & patent analysis; WO2022038052

PU recycling process deep dive – Covestro new process

Covestro recently published new patents relating to hydroglycolysis, leading to much easier processes allowing recovery of products at lower costs.

Covestro process



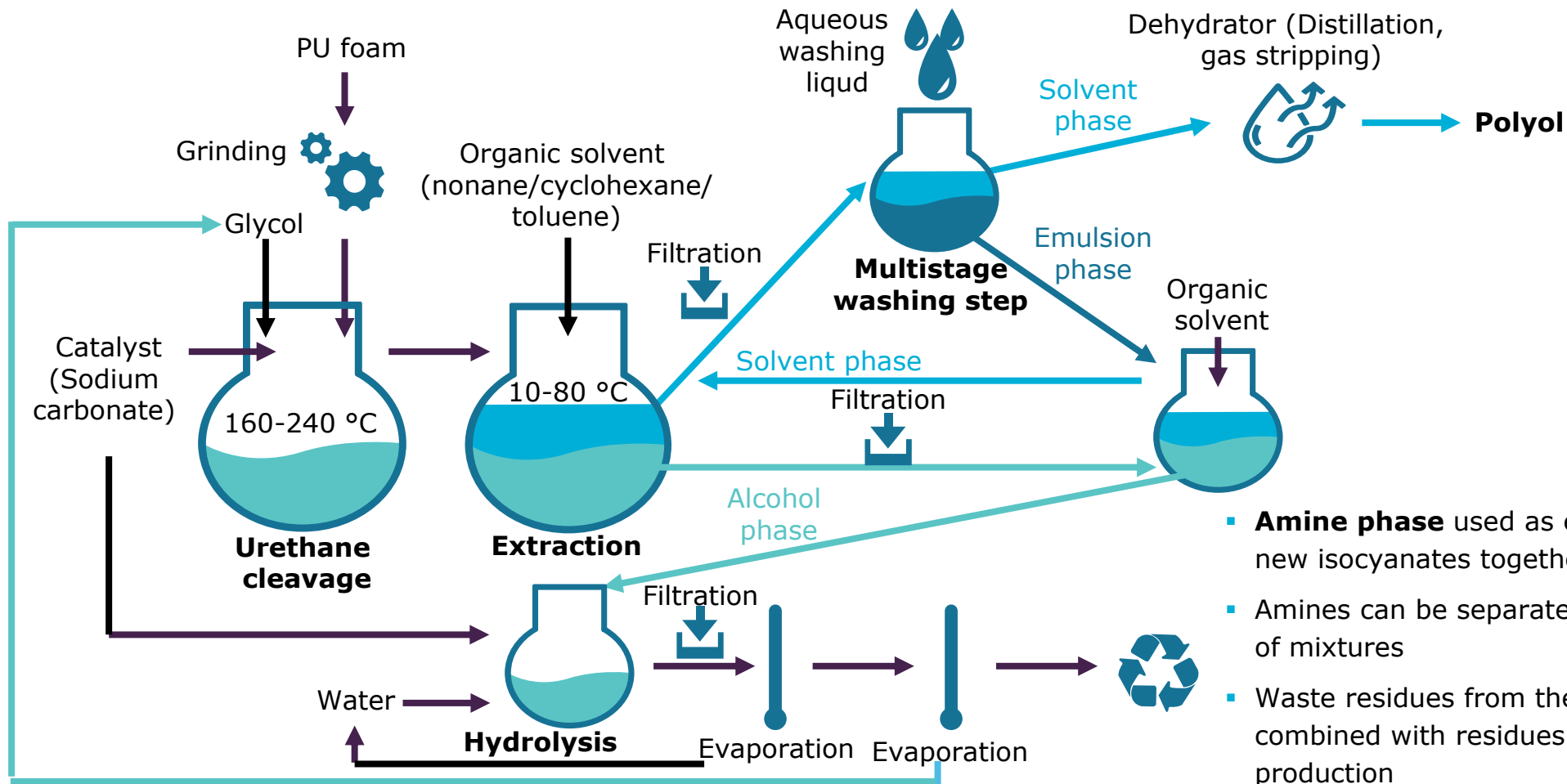
Sources: Interviews, desk research & patent analysis; WO2022171586A1

PU recycling process deep dive – Covestro 1st generation

Pre-read

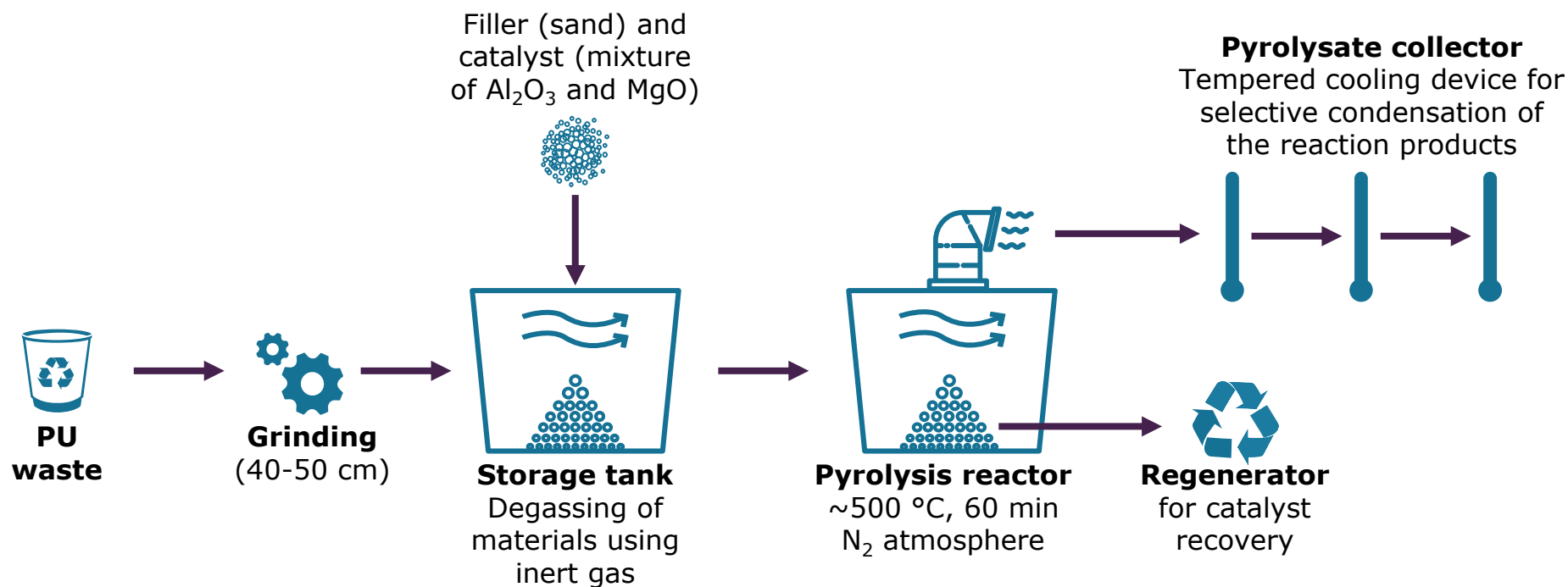
Covestro used glycolysis followed by hydrolysis to recover polyols as well as educts for the isocyanate production. Intensive solvent extraction led to high cost.

Covestro process



Sources: Interviews, desk research & patent analysis; US20220251328A1

Covestro published a patent for a recycling process based on pyrolysis recently, allowing the recovery of compounds like especially anilines from PU waste.



- PU foam to be processed is rigid foam based on **MDI preferably**
- Recovered products include **aniline, N-methylaniline, mMDA and pMDA**
- Preferred catalysts to be used are metal oxides, especially mixtures of Al_2O_3 and MgO

- This material has been developed during a six month effort in an iterative process between Schlegel und Partner & the client.
- Target of this market study was to get insights in the market development and price forecast for recycled polyurethane from end-of-life (EoL) mattresses and upholstery.
- The objective of the project included the understanding the current and expected market size for EoL polyurethane and the respective technologies, getting insights into the cost position of the different recycling technologies and developing an outlook on potential price levels for EoL in the future together with drawing cost curves of the European EoL PU market
- 90 Interviews with market participants, up-stream & downstream: mech. recyclers, chem. recyclers, foamers, retailers, dismantlers, waste management, „general market experts“...
- Model of EU flexible foam market and consumption by mattress type (single / multiple layer / spring)
- Derived EoL PU feedstock availability for flexible foam recycling differentiating by source (from PIW, Mattress, upholstery) and foam type (slabstock, high resilience (HR) & viscoelastic)
- Cost & revenue analysis of competing chemical & mechanical recycling technologies based on detailed process models
- Hypothesis on future EU legislation and impact on PU foam demand (virgin vs recycle)
- Prediction of EoL foam consumption / access per competing recycling technology (cost curve)
- Consumer survey (6 countries with 300 participants each) on sustainability willingness-to-pay for mattresses & upholstery
- This report is the full documentation of all findings, analyses & assumptions, with an executive & management summary on the following pages.
- Any questions regarding this material should be directed to Thorsten Leupold (Thorsten.Leupold@schlegelundpartner.de), Dr. Thorsten Bies (Thorsten.Bies@schlegelundpartner.de), Tobias Lutz (Tobias.Lutz@schlegelundpartner.de) & Dr. Annika Trümpler (Annika.Truempler@schlegelundpartner.de)

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Dr. Annika Trümpler

Executive Partner

+49 6201 9915 74

Annika.Truempler@schlegelundpartner.de



Thorsten Leupold

Partner, Director Chemicals

+49 6201 9915 16

Thorsten.Leupold@schlegelundpartner.de



Dorothea Slevogt

Consultant Technical Textiles

– Senior Specialist

+49 6201 9915 76

Dorothea.Slevogt@schlegelundpartner.de



Tobias Lutz

Senior Consultant Chemicals

+49 6201 9915 17

Tobias.Lutz@schlegelundpartner.de



Dr. Thorsten Bies

Consultant Chemicals

+49 6201 9915 77

Thorsten.Bies@schlegelundpartner.de



Schlegel und Partner GmbH
Ludwigstrasse 6
69469 Weinheim
Germany

Phone: +49 6201 9915 – 0
Fax: +49 6201 9915 – 99
info@schlegelundpartner.de

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All rights reserved

Executive Partners:

Dierk Plümer
Dierk.Plumer@SchlegelundPartner.de

Dr. Annika Trümpler
Annika.Truempler@SchlegelundPartner.de

