Thermomechanical Recycling of Textiles: State of the Art

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Thermomechanical Recycling of Textiles: State of the Art

THERMOMECHANICAL RECYCLING BASICS

STRENGTHS, LIMITATIONS & KEY TECHNICAL CHALLENGES

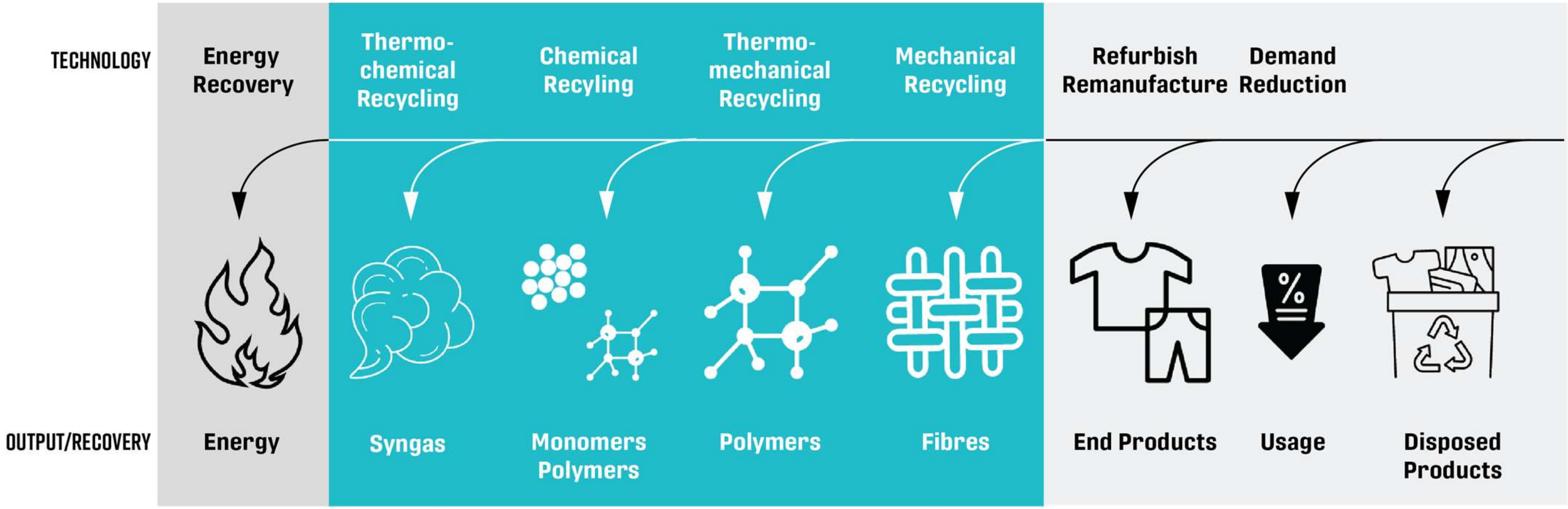
STATE OF THE ART SOLUTIONS & INDUSTRY EXAMPLES

CENTEXBEL RESEARCH: INSIGHTS & OUTLOOK

THERMOMECHANICAL RECYCLING BASICS

Textile recycling technologies

“Different recycling technologies enable recovery at various levels. Higher quality recycling often comes with higher environmental impact — the challenge is finding the long-term balance.”



Thermomechanical recycling technology

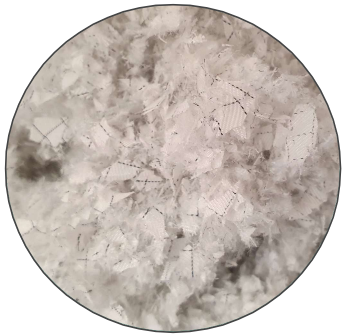
Process using heat to melt thermoplastic materials and recover the polymers in the form of regranulate or fibres.

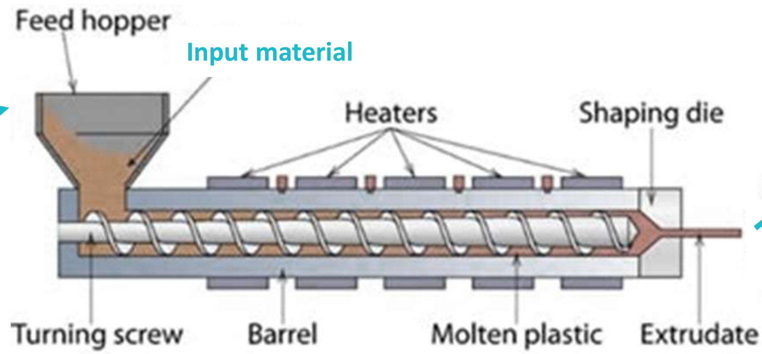
Technology maturity level depends on the type and quality of the feedstock:

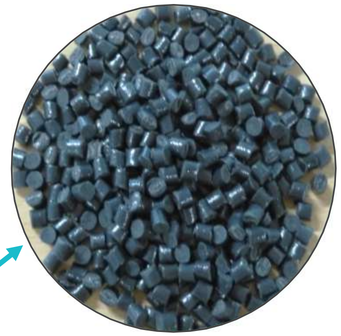
- **Plastics**: fully mature technology (TRL 9).
- **Clean industrial textile waste**: industrial deployment in place (TRL 8–9).
- **Post-consumer textiles**: pilot/demo lines exist, emerging to pre-commercial (TRL 6–8), dependent on feedstock quality.

Process basics

Pretreatment
Collection & sorting, shredding, washing/cleaning, compacting…







Recycling inputs & outputs

Input

Theoretical

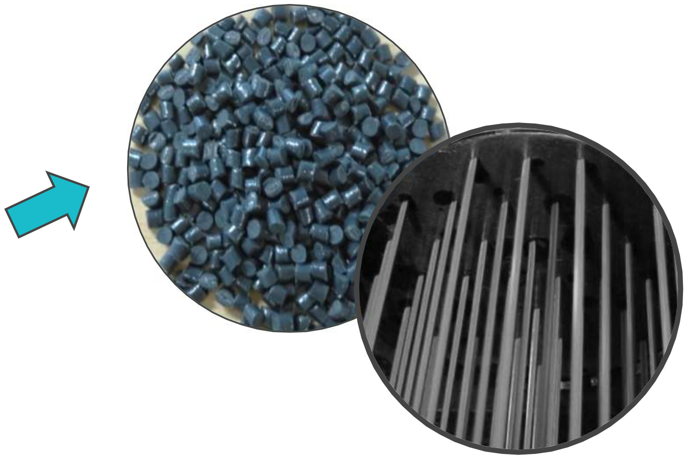
Any thermoplastic material (PET, PP, PE, PA, PLA…)

In practice

Polymer blends and contaminants require careful consideration, especially when melt spinning is the goal

Output

- Polymer pellets or textile fibres
- Polymer composition, chemical content, and color remain the same as the input, except for:
  - Volatile components removed through degassing
  - Non-melting particles filtered out



STRENGTHS, LIMITATIONS & KEY TECHNICAL CHALLENGES

Advantages & limitations of the process

Pros

- Cost-effective, efficient, and well-established process
- Easily implemented
- Minimal emissions during processing – only volatile contaminants (e.g. from disperse dyes or polymer degradation) are released.

Cons

- **Low bulk density:** Using textiles as input makes feeding into the extruder more challenging.
- **Viscosity challenges**: Polymer degrades with each cycle, and melt spinning is highly sensitive to molar mass/viscosity.
- **Contaminations:**
  - Colourants remain in the polymer, requiring **colour** sorting or the addition of dark pigments.
  - Non-volatile chemicals persist in the recycled material, potentially conflicting with **REACH** regulations.
  - Strict **feedstock requirements**: Even low contamination levels can affect melt spinning quality.

➔ Mainly applied to production waste and specific, well-defined post-consumer waste streams.

Challenge 1 – Low bulk density

Shredded textile waste has very low bulk density making feeding difficult

Challenge 1 – Low bulk density

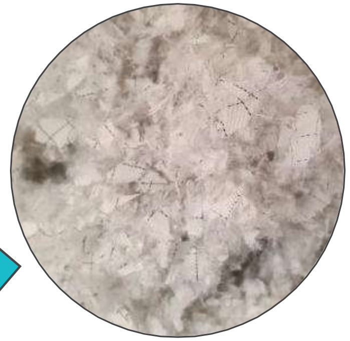
Solutions:

- Densification via compacting equipment
- Adapted feeding systems
- Integrated shredder-extruder combinations
- Preconditioning units with compacting function

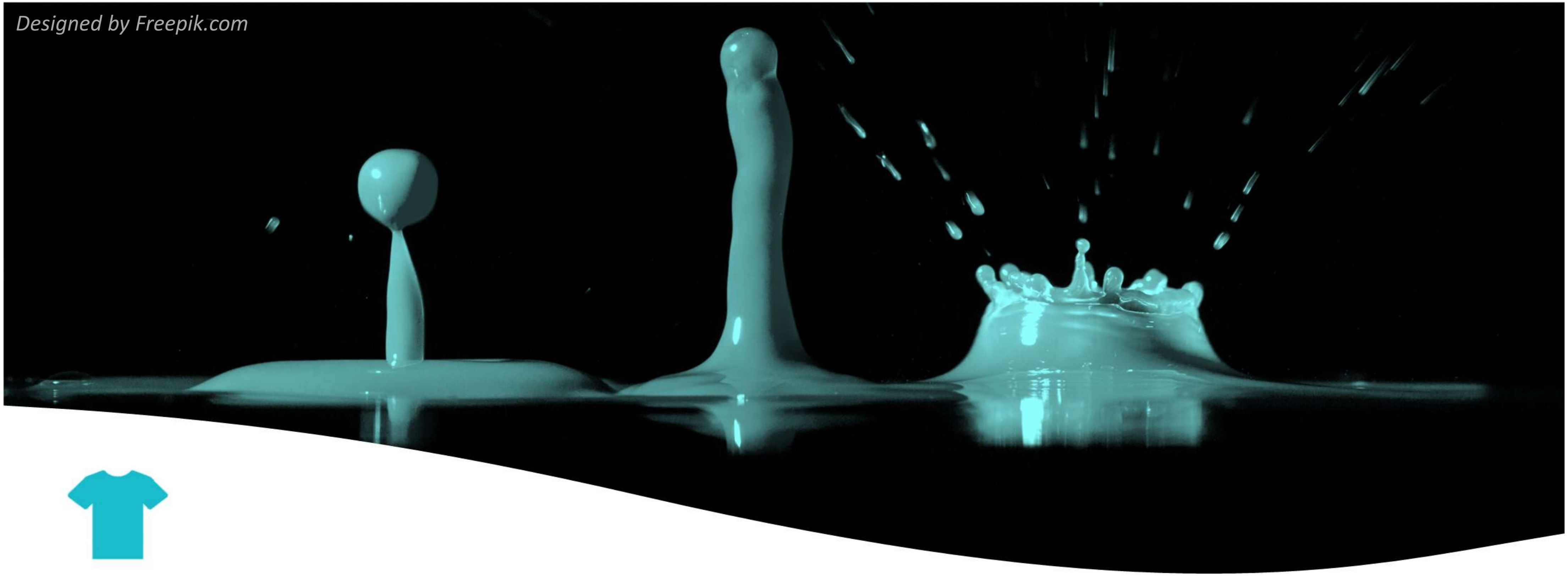
Results:

- ☑ Improved throughput & more stable processing
- ☑ Allowing continuous operation

Addressing low bulk density challenges



Flat die pelleting press



Challenge 2 – Viscosity

Viscosity loss during recycling can compromise melt spinning performance

Key challenges – Viscosity

Viscosity loss during recycling can compromise melt spinning performance.

Melt spinning requires a controlled IV, too low or unstable IV leads to:

Extrusion instabilities

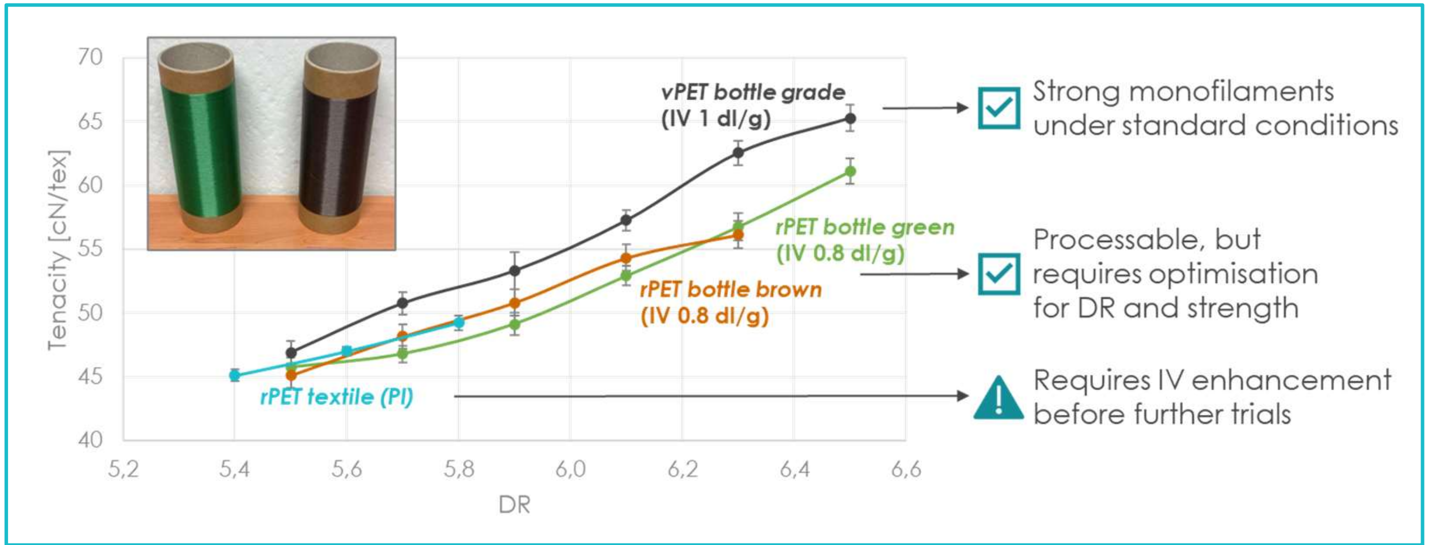
No melt strength

Weak fibres/ Filament fracture

Inconsistent dyeing

DigInTraCE

Case study: Monofilament extrusion



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Key challenges – Viscosity

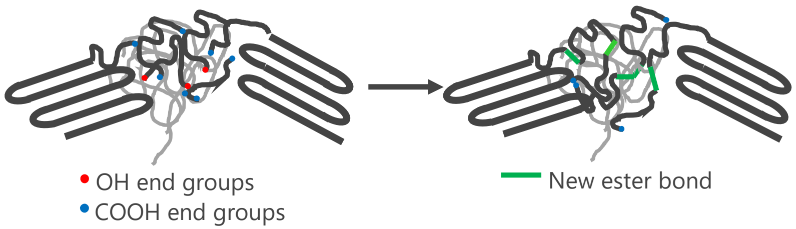
Viscosity loss during recycling can compromise melt spinning performance.

Solutions for polyester

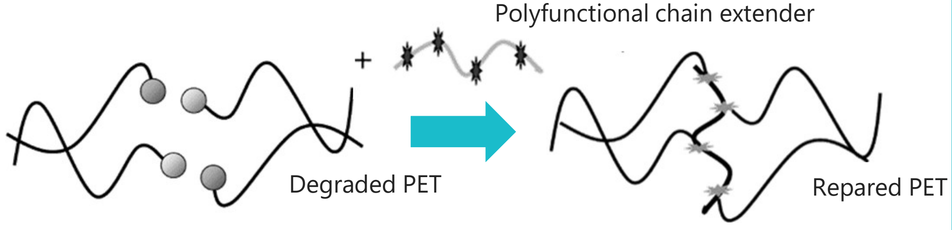
- *Prevent*
  - Proper drying before processing
  - High-vacuum degassing
- *Restore*
  - Solid-State Polycondensation (SSP)
  - Liquid-State Polycondensation (LSP)
  - Chain extension

	SSP	LSP	Chain extenders
State of PET	Solid	Liquid *(melt)*	Liquid *(during melt processing)*
Environment	Inert gas *(N_2)* or vacuum *(≤10 mbar)*	High vacuum *(≥1 mbar)*	Atmospheric *(during extrusion)*
Temperature	200-240°C	270-290°C	260-280°C
IV increase	0.01-0.06 dl/g per hour	0.01-0.1 dl/g per minute	0.1-0.3 dl/g in minutes

SSP/LSP condensation reaction



Chain extension



(M. Villalobos, et al., 2006)

Key challenges – Viscosity

PET2VALUE
ICON project

Case study: Extreme IV boost with chain extenders

Transforming PI PET flakes into high-quality rPET for monofilaments

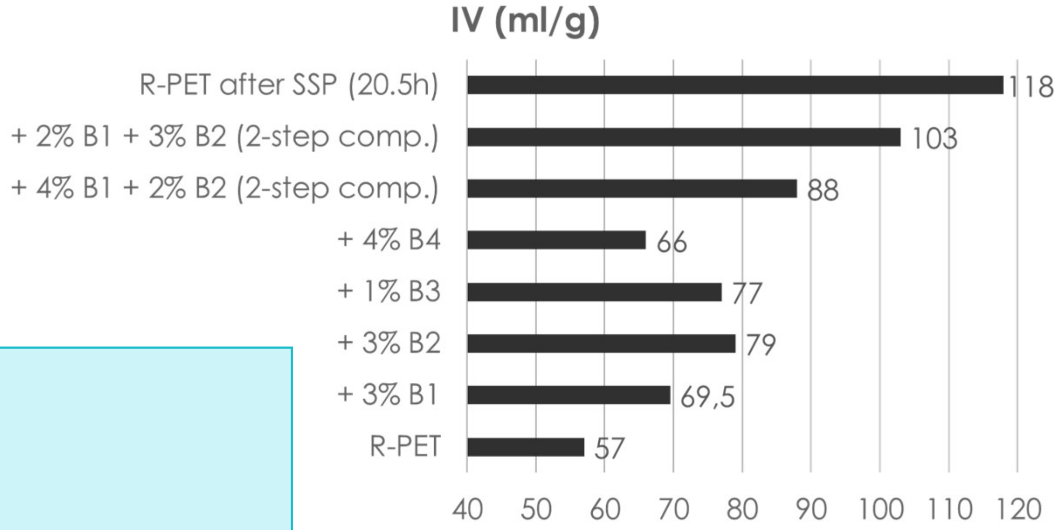
PET flakes

IV = 57 ml/g

PET pellets

Target IV = 100 ml/g

Impact of different types of chain extenders on the IV of rPET



Conclusions

- ☑ **Instant** effect – can be added during extrusion
- ☑ Improved processability & fibre tenacity
- ⚠ Challenges: difficult to control, risk of inhomogeneity & gel formation

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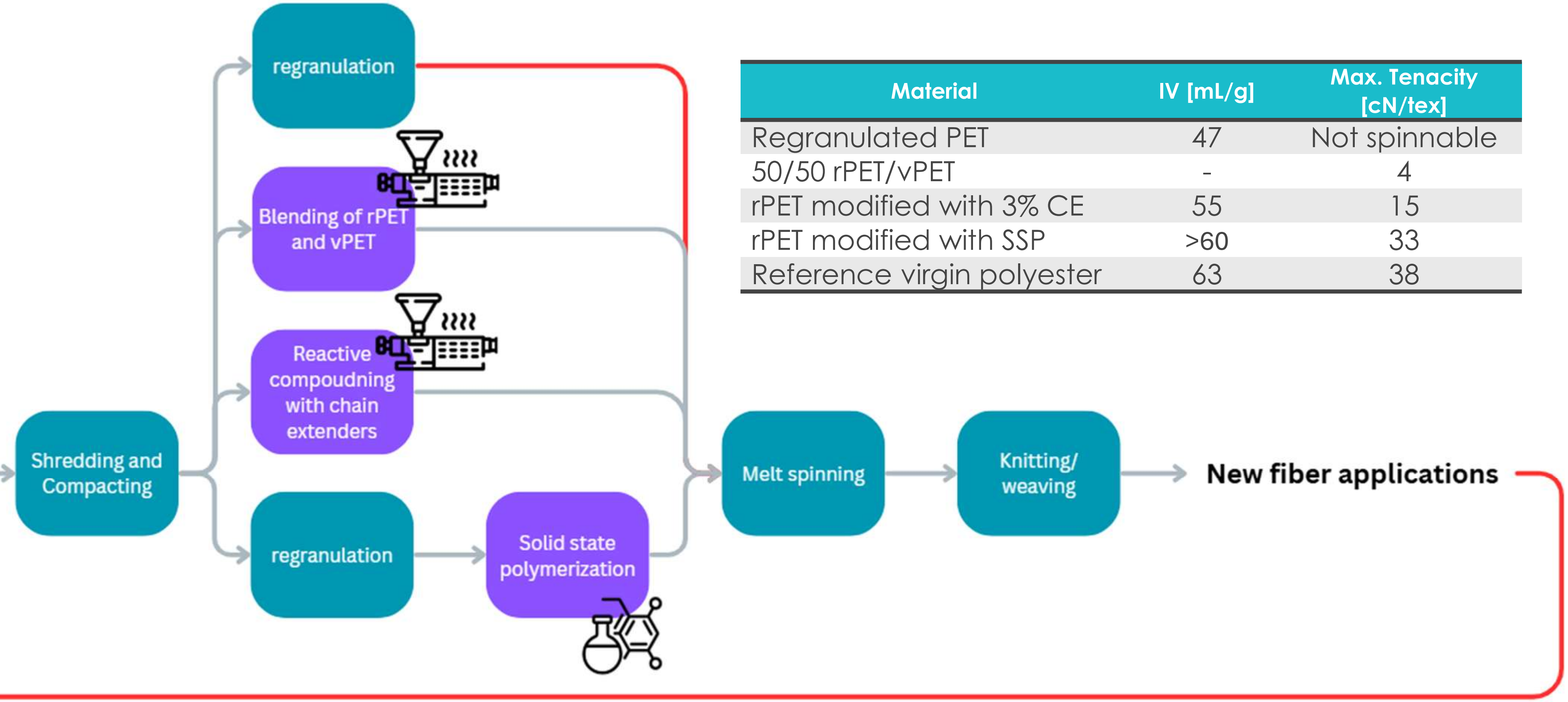
Benchmarking different IV modification methods

PRecycling

post-industrial curtain waste



Material	IV [mL/g]	Max. Tenacity [cN/tex]
Regranulated PET	47	Not spinnable
50/50 rPET/vPET	-	4
rPET modified with 3% CE	55	15
rPET modified with SSP	>60	33
Reference virgin polyester	63	38

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This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101058670.

Viscosity challenges – Key takeaways

Prevention

- Drying to avoid hydrolysis
- Pre-conditioning with vacuum reactor

➔ *Keeps IV stable before extrusion*

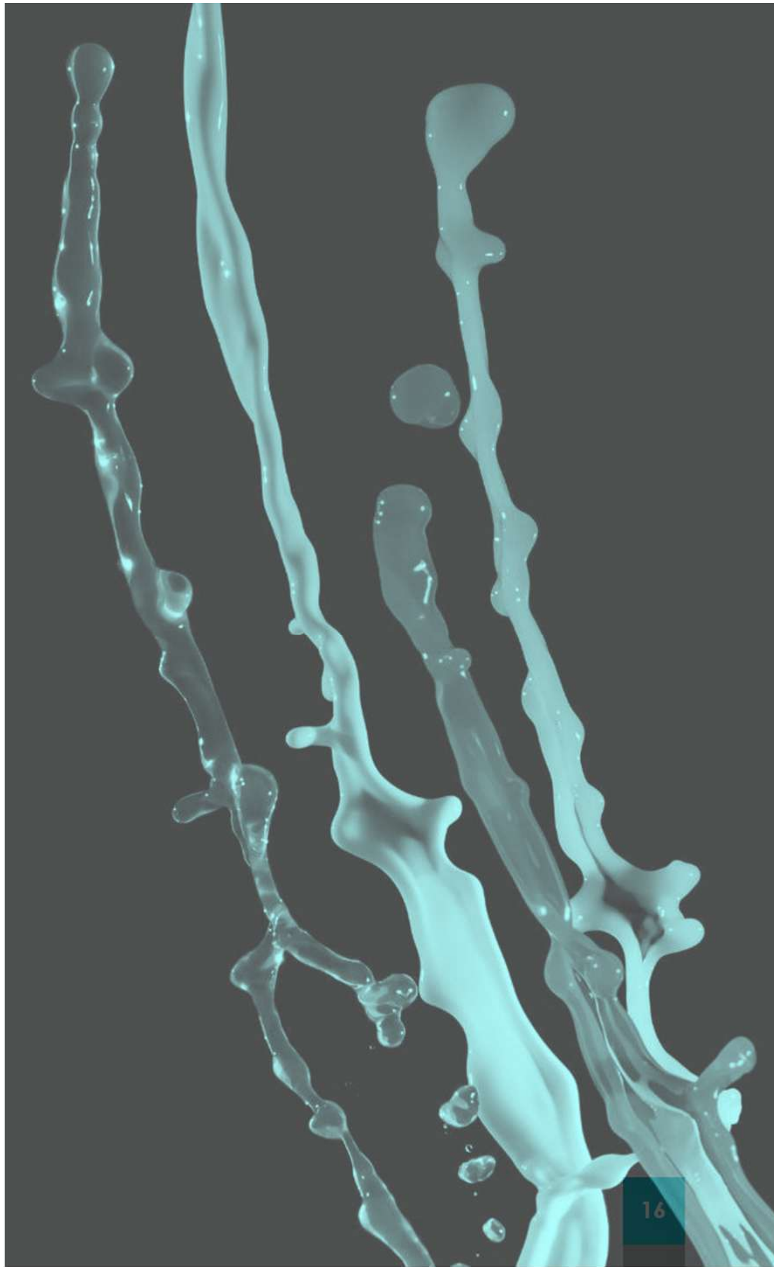
Restoration

- SSP: controlled & reliable but slow
- Chain extension: instant, but risk of crosslinking & dose dependency

➔ *Both can achieve high IV boost*
➔ *Enabling more stable melt spinning & stronger fibres*

Outlook

- Matching solution to input quality & final product specs



Challenge 3 – Contaminations

Foreign matter, dyes & additives reduce recyclate quality and reprocessability

Key challenges – Contaminations

Foreign matter, dyes & additives reduce recyclate quality and reprocessability

Melt spinning is highly sensitive to contaminations causing processing issues and quality loss

Particulate matter

Other additives and finishings

Spin finishes, dyes

- Pressure buildup and blockage
- Unstable process
- Polymer degradation & IV drop
- Filament fractures
- Discolouration
- Reduced tenacity

Solutions

- Washing of (production) waste
- High-vacuum degassing for volatiles
- Advanced fine filtration systems

Nevertheless…

Contamination limits remain strict, particularly for melt spinning.

Key enablers: advanced sorting, tracers/DPP & ecodesign
➔ cleaner, mono-material flows

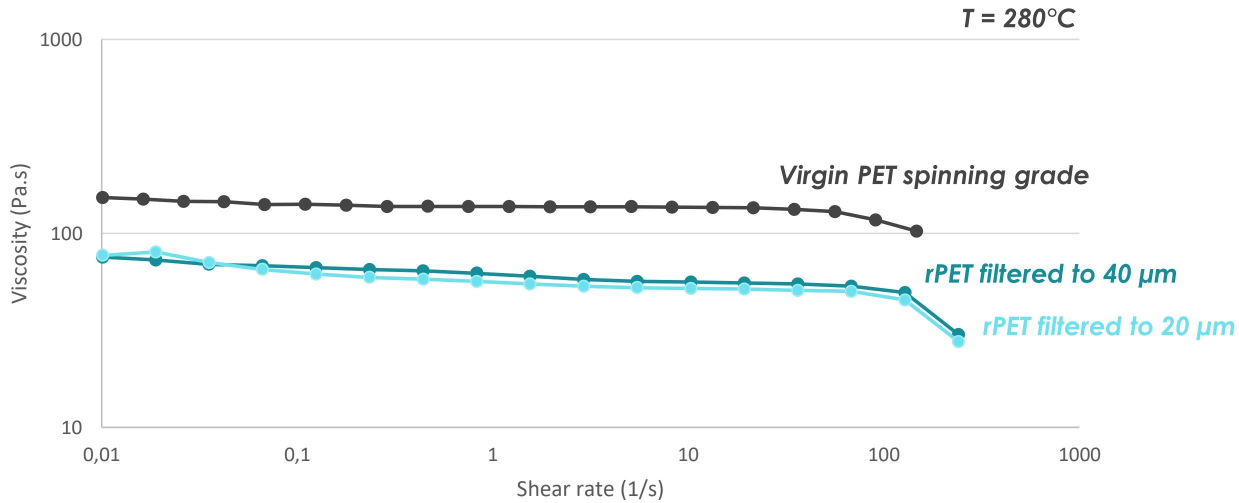
The case of wool contamination

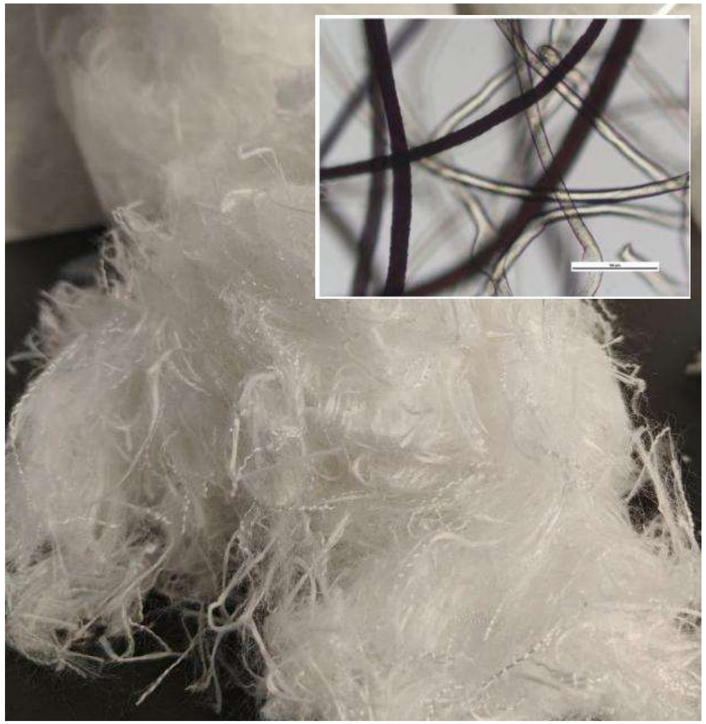
100% PES post-production cutting waste; IV 68 ml/g

Multifilament spinning initially running smooth until more & more fractures, pressure buildup & finally leakage at the spinneret due to clogged filters

➔ Wool contamination from mechanical recycling tearing line

➔ Melt filtration down to 20 µm





Result

⚠ Reduced IV complicates spinning

⏭ SSP to boost IV

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101091575

Key challenges – Contaminations

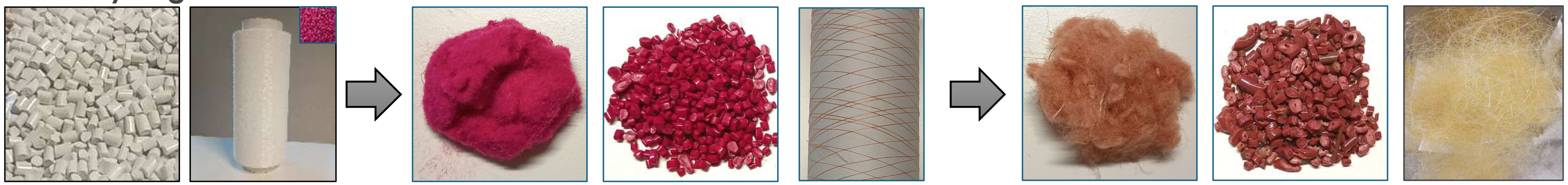
Case study: Effect of colorants on recycling

Mass coloration

IV = 67 *IV = 59* *IV = 51* *T = 21 cN/tex*

Experiments ongoing

Batch dyeing



IV = 67 *IV = 62* *IV = 52* *T = 18 cN/tex* *IV = 50* *IV = 48*

No bobbin, too unstable

Impact on IV & reprocessing: similar for both methods

Impact on color:
- Better retention with mass coloration, but
- Easier to bleach pre-recycling with batch dyeing

Addressing contamination challenges at lab scale

Development of contamination removal via $scCO_2$ extraction

Supercritical CO_2

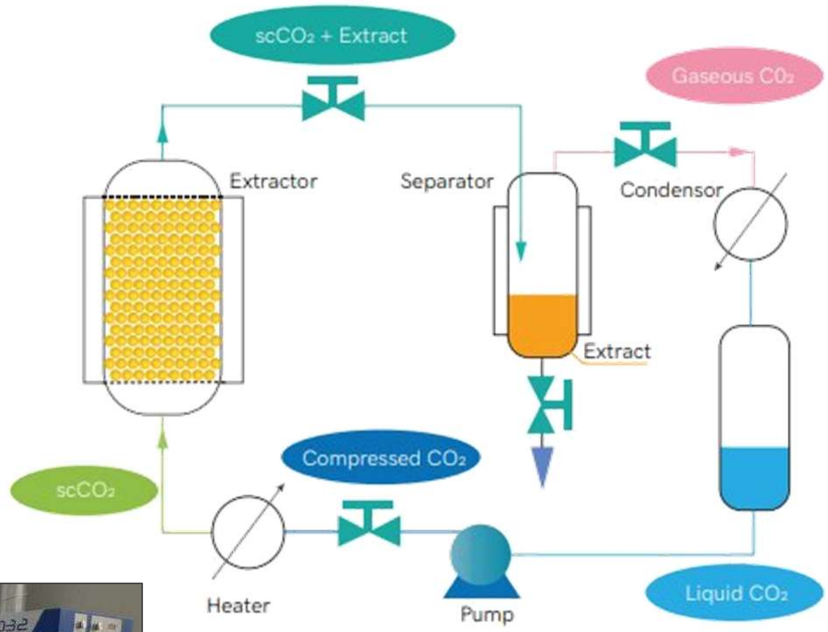
- combines the advantages of a gas and a liquid
- when heated to a temperature (>31.1°C)
- and pressure (>73.8 bar) above its critical point.

Properties

Green solvent, non-polar, easily recyclable, non-toxic, non-flammable

Applications

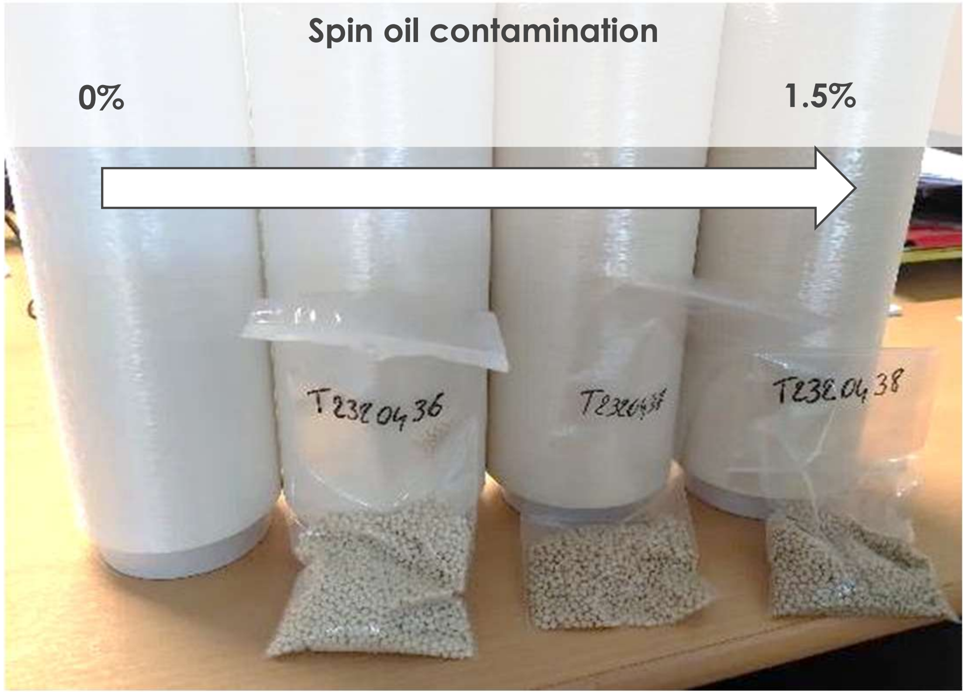
removal of odors, additives, dyes…



Case studies with $scCO_2$

Removing spin oils prevents degradation, processing issues and discoloration

Spin oil removal



Results

- ☑ Removal via $scCO_2$ with **94.6% efficiency**
- ⏭ Next challenge = upscaling

Contamination challenges – Key takeaways

Current solutions

- Vacuum degassing – effective for volatiles
- Fine melt filtration – effective for particles

➔ *Both applied in-house, each with possibilities & limitations*

Emerging options

- $scCO_2$ extraction – Promising lab-scale results

➔ *Next step: upscaling & inline integration*

Outlook

- Sorting & separation technologies
- Tracers & digital product passports

➔ *Crucial to expand feedstock beyond post-industrial sources*

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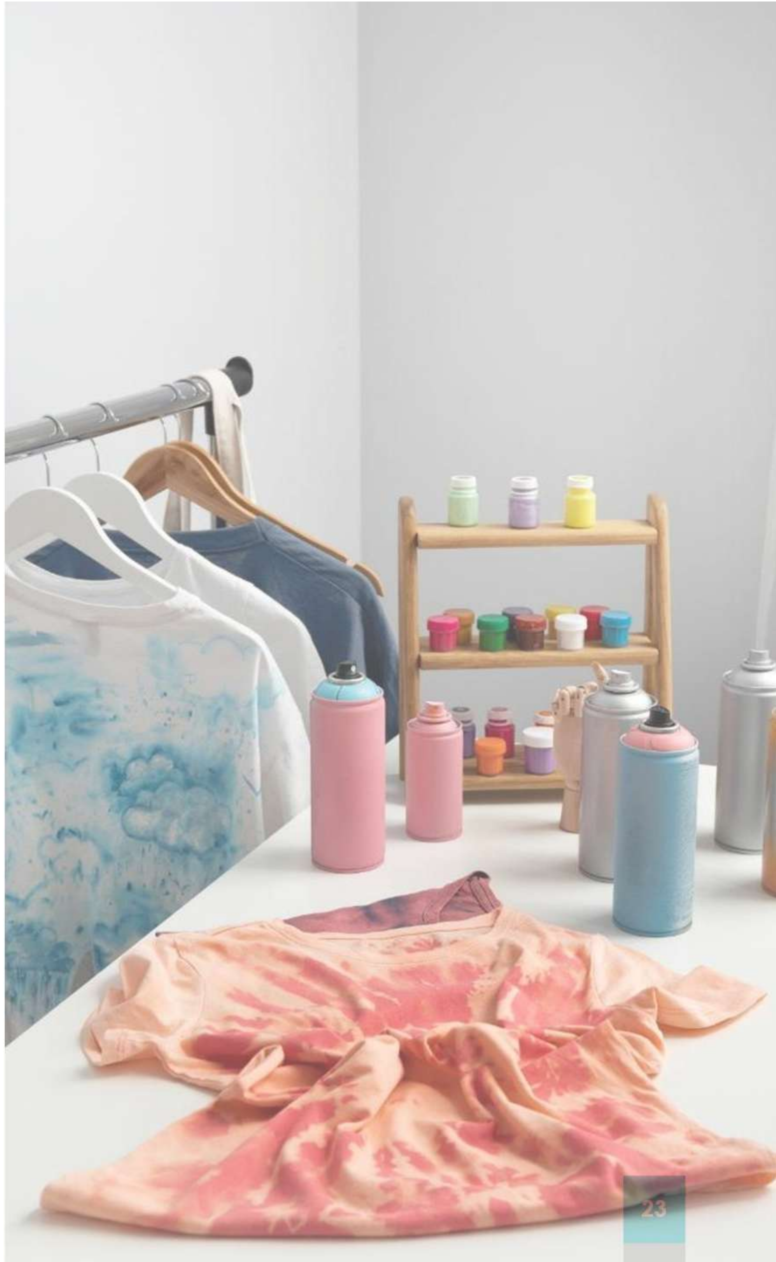


STATE OF THE ART SOLUTIONS & INDUSTRY EXAMPLES

Key players in thermomechanical recycling technology

State of the art solutions

- Integrated shredders and size-reduction units
- Material preparation, preconditioning and feeding units integrating cutting, homogenization, heating, drying, compacting, buffering and dosing
- High-vacuum degassing
- Fine filtration down to 20µm
- SSP reactors & LSP systems for PET IV homogenisation and increase
- Inline IV and melt-quality monitoring & control units
- Inline spinning

Industrial technology providers

BB ENGINEERING The Valueneering Company®

gneuß

NGR PLASTIC RECYCLING TECHNOLOGIES

Starlinger

EREMA PURE LOOP MEMBER OF EREMA GROUP

Auping

auping

Auping circular mattress

100% PET polyester textiles and steel wire pocket springs connected with Niaga®, a nontoxic reversible adhesive

RetourMatras

Collects, sorts, and separates materials

INDORAMA VENTURES
WELLMAN INTERNATIONAL LTD

Converts polyester textile components back into rPET pellets & staple fibres

twe group
smart nonwoven solutions

Production of nonwovens

Project Re:claim

Joint venture between Salvation Army Trading Company and Project Plan B

First commercial-scale, post-consumer polyester thermomechanical recycling plant

Capacity: 3000 tonnes per annum

Feedstock

- *Mono-fibre polyester garments*
- *Banners & flags*
- *Post-consumer polyester clothing*
- *Hospitality textiles*
- *Soft furnishings*
- *Uniforms & workwear*
- *Bedding & linens*

THE SALVATION ARMY SALVATION ARMY TRADING COMPANY

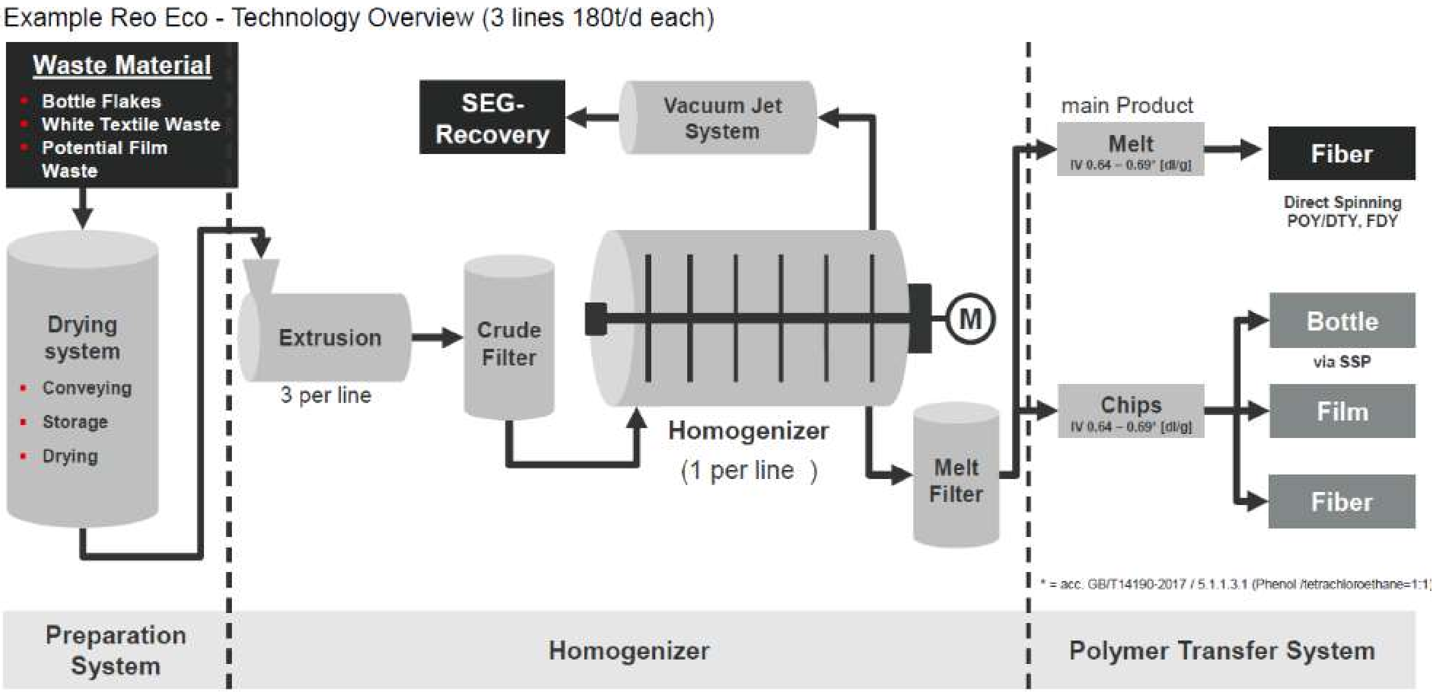
PROJECT PLAN B

PURE LOOP MEMBER OF EREMA GROUP

Oerlikon Barmag/Reo eco

Reo eco thermomechanical recycling facility (China)

540t/day direct spinning thermomechanical recycling ➔ 250,000 ton filament yarn per year



Other industrial examples

Antex (ES)
Synthetic yarn producer thermomechanically recycling polyester for reintroduction into spinning.

RE&UP (NL–TR)
Circulartech company using advanced thermomechanical and mechanical processes to separate and convert polycotton streams into new fibres.

Muovi (FR)
Startup performing thermo-mechanical recycling of polyester waste into granules.

Nurel (ES)
Polymer, fiber and biopolymers producer thermomechanically recycling nylon production waste into 100% recycled PA6 yarn.

Unifi (US)
Bottle-to-fibre recycler since 2007; now also performing fibre-to-fibre polyester recycling.

Other industrial examples – open loop

Mapea (FR)
Recycling company converting rejected textiles and EOL garments into high-value technical compounds for use in the plastics industry.

PETEX

PETEX est une matière qui valorise plus de 90% de PET issu du recyclage textile

Il se substitue au : PET, PBT, ABS

REGAFIB

REGAFIB est un alliage de PP ou de PA6 renforcé par une base en coton ou polycoton issue du recyclage textile

Il se substitue au : PP ou PA vierges, chargés en talc ou en verre

REGAMID

REGAMID est un alliage qui valorise jusqu'à 90% le polyamide et mélange issus du recyclage textile

Il se substitue au : PA

beaulieu needle felt

Beaulieu Rewind (BE)
Latex-free, mono-material PP needle-felt carpet for event and contract use, designed for full recyclability and processed into clean PP recyclate via specialised recycling partners.

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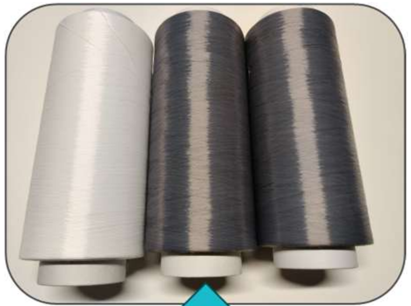
CENTEXBEL RESEARCH: INSIGHTS & OUTLOOK

Centexbel infrastructure – recycling flow



Shredding → Compacting → Compounding/ Pelletization → Melt spinning

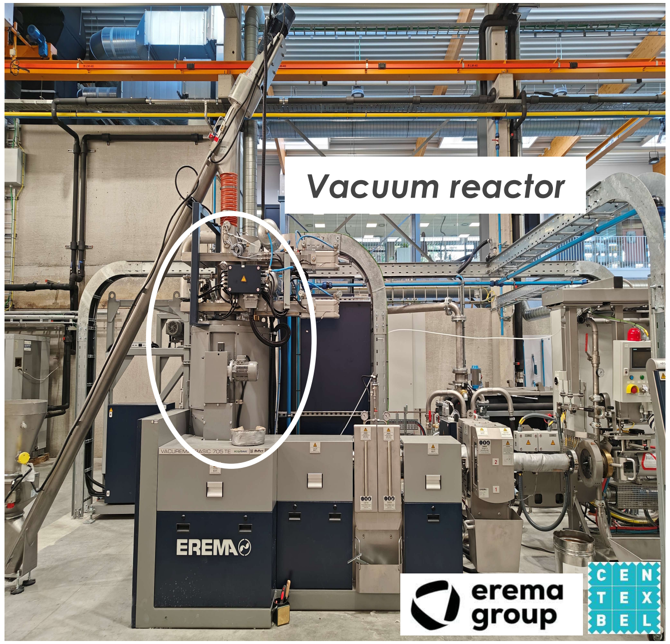
Addressing viscosity challenges – our toolbox

SSP lab scale unit

Boosts IV through solid-state reaction

Compact VACUREMA®

Batch SSP mode for minor IV enhancement



Chain extenders

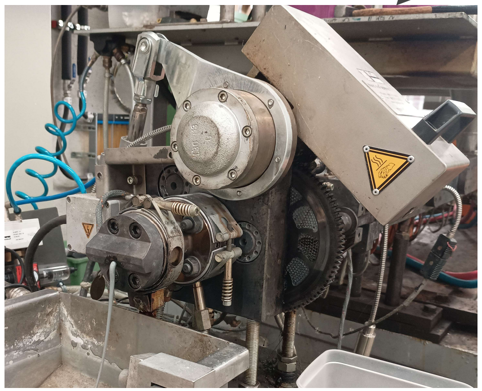
In compounding or during filament extrusion

Addressing contamination challenges at pilot scale

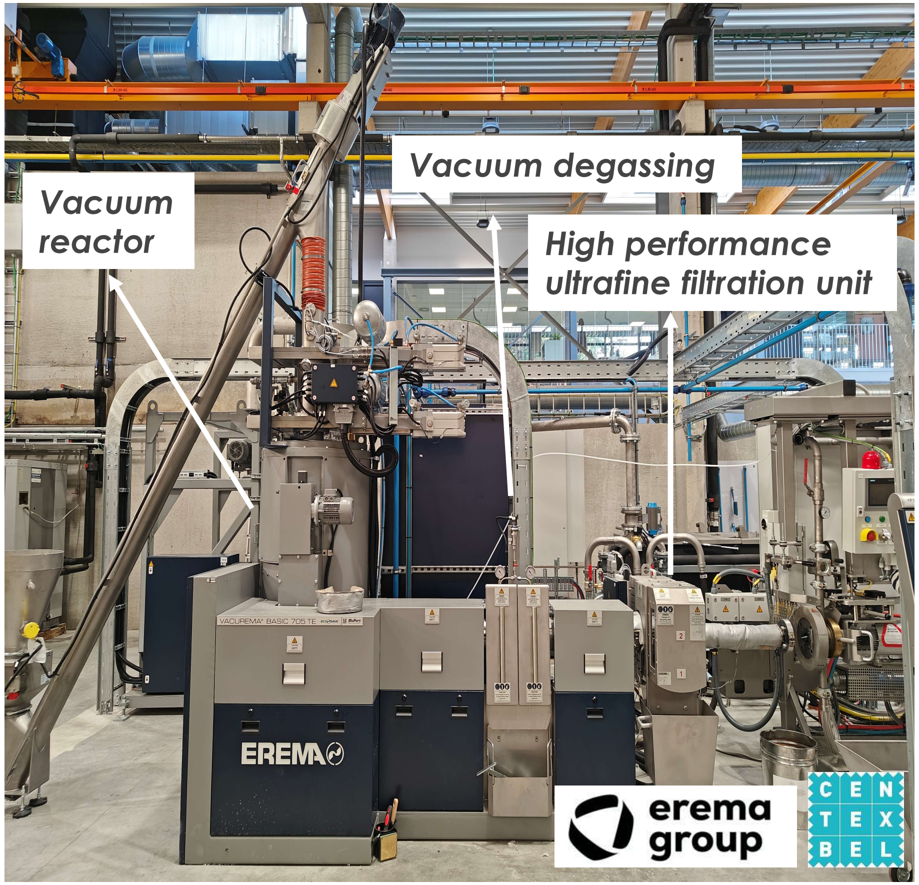
Removal of volatile and non-melting contaminants

Twin screw compounder

Vacuum degassing



Rotating screen melt filtration unit



Compact VACUREMA® line

CISUTAC
Circular and Sustainable Textiles and Clothing

tExtended

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Impact of the recycling process on multifilament extrusion and yarn quality

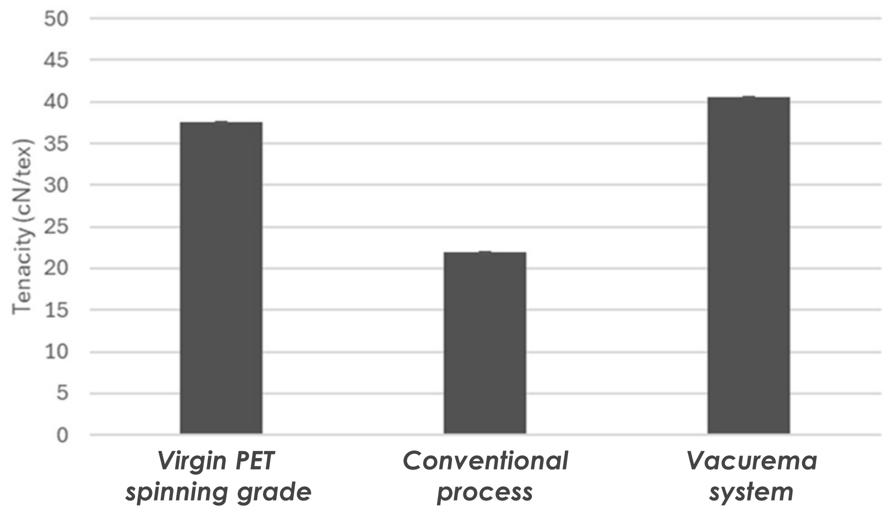
Multifilament extrusion

☒ Conventional process with melt filtration
➔ Not processable, melt viscosity too low

⚠ Conventional process without melt filtration
➔ Pressure build-up & leaks at the spinplate

☑ Vacurema® system
➔ Stable extrusion process

Yarn tenacity



Conclusion – 1st Vacurema trial:

☑ Vacurema enables stable extrusion and restores virgin-like tenacity, outperforming the conventional process

⏭ Exploring the capabilities and limitations of the technology with additional waste streams

CISUTAC
Circular and Sustainable Textiles and Clothing

Acknowledgements

DigInTraCE

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PET2VALUE ICON project

AGENTSCHAP INNOVEREN & ONDERNEMEN

Financed by Vlaio (Project HBC.2020.2522)

ReCoTex

ADVANCED THERMO-MECHANICAL RECYCLING OF COLOURED THERMOPLASTIC TEXTILE WASTE

VLAIO cornet

Cornet project, financed by VLAIO (Flanders, n° HBC.2023.0173) and AIF (Germany)

CISUTAC

Circular and Sustainable Textiles and Clothing

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tExtended

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Interreg

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CrossS3 RE-APS

VLAIO

Wallonie recherche SPW

met de steun van west-vlaanderen de gedreven provincie

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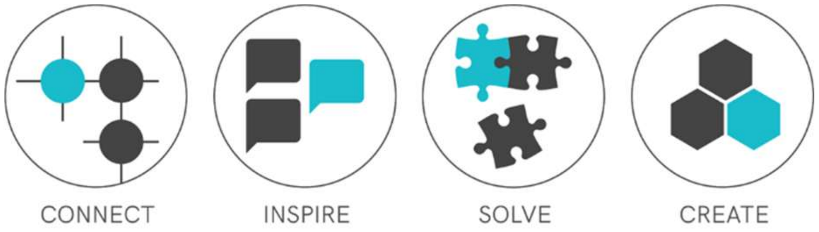

Thank you!

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