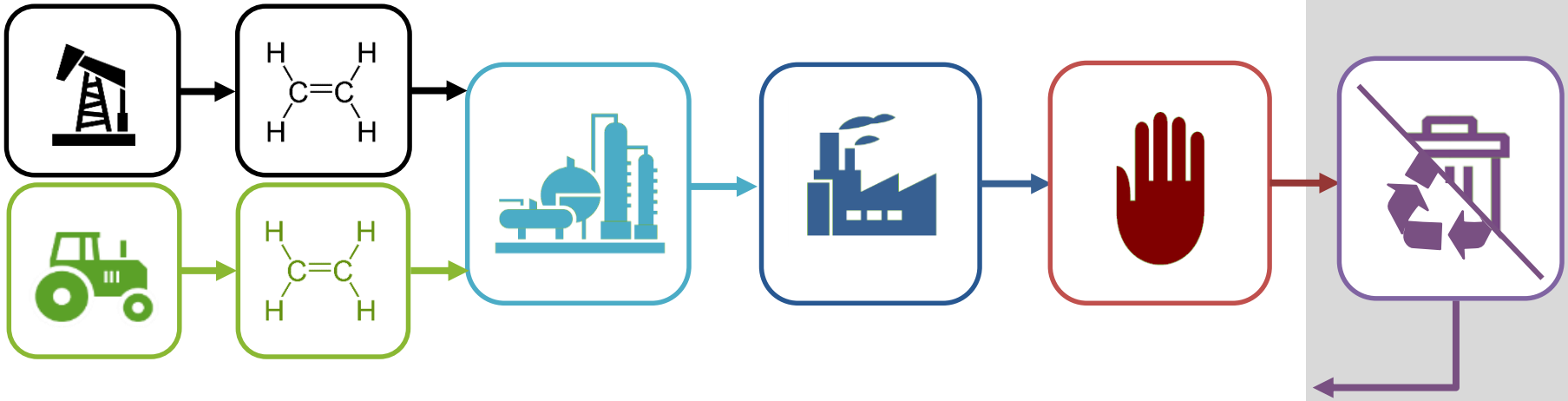
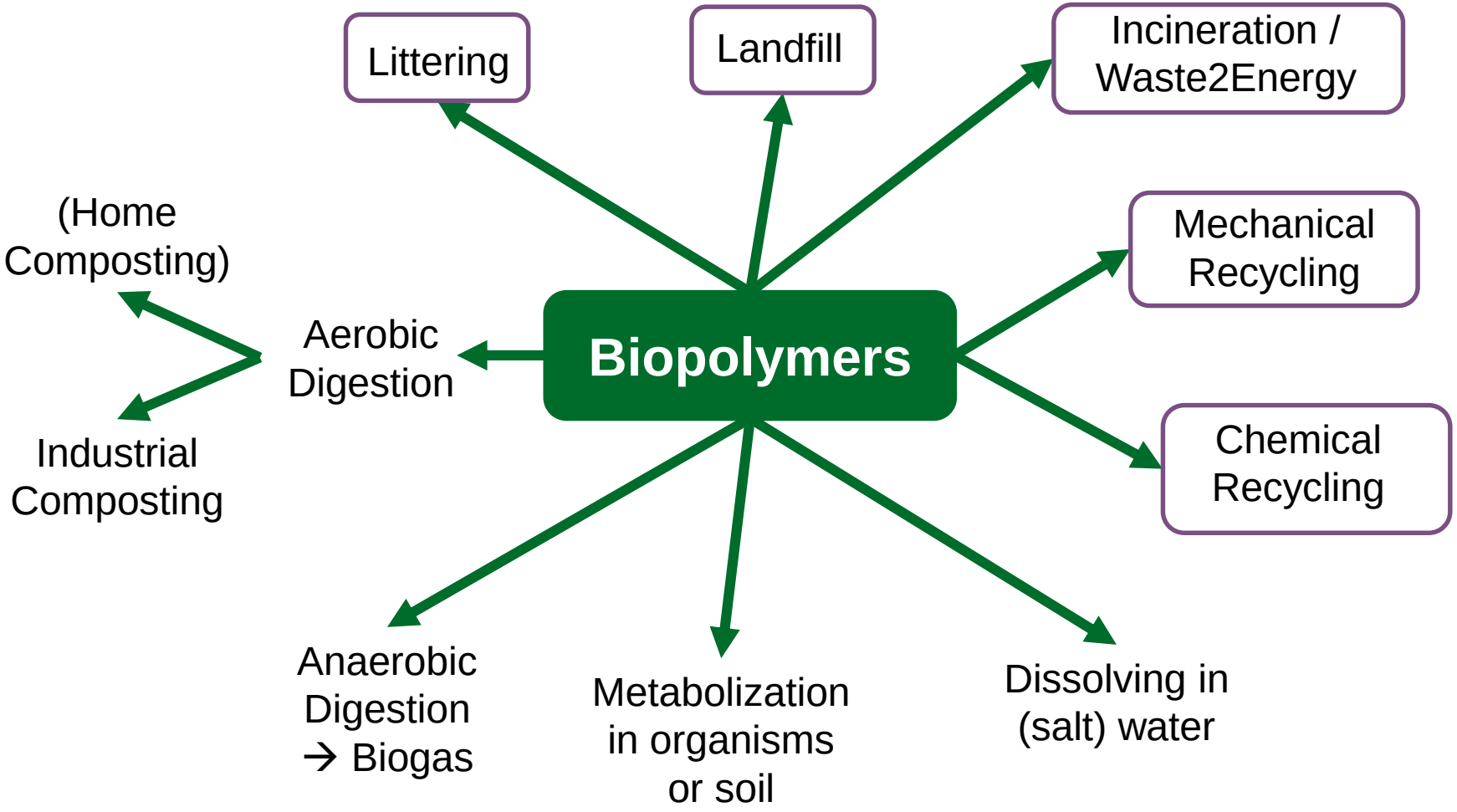
Recycling of Biopolymers



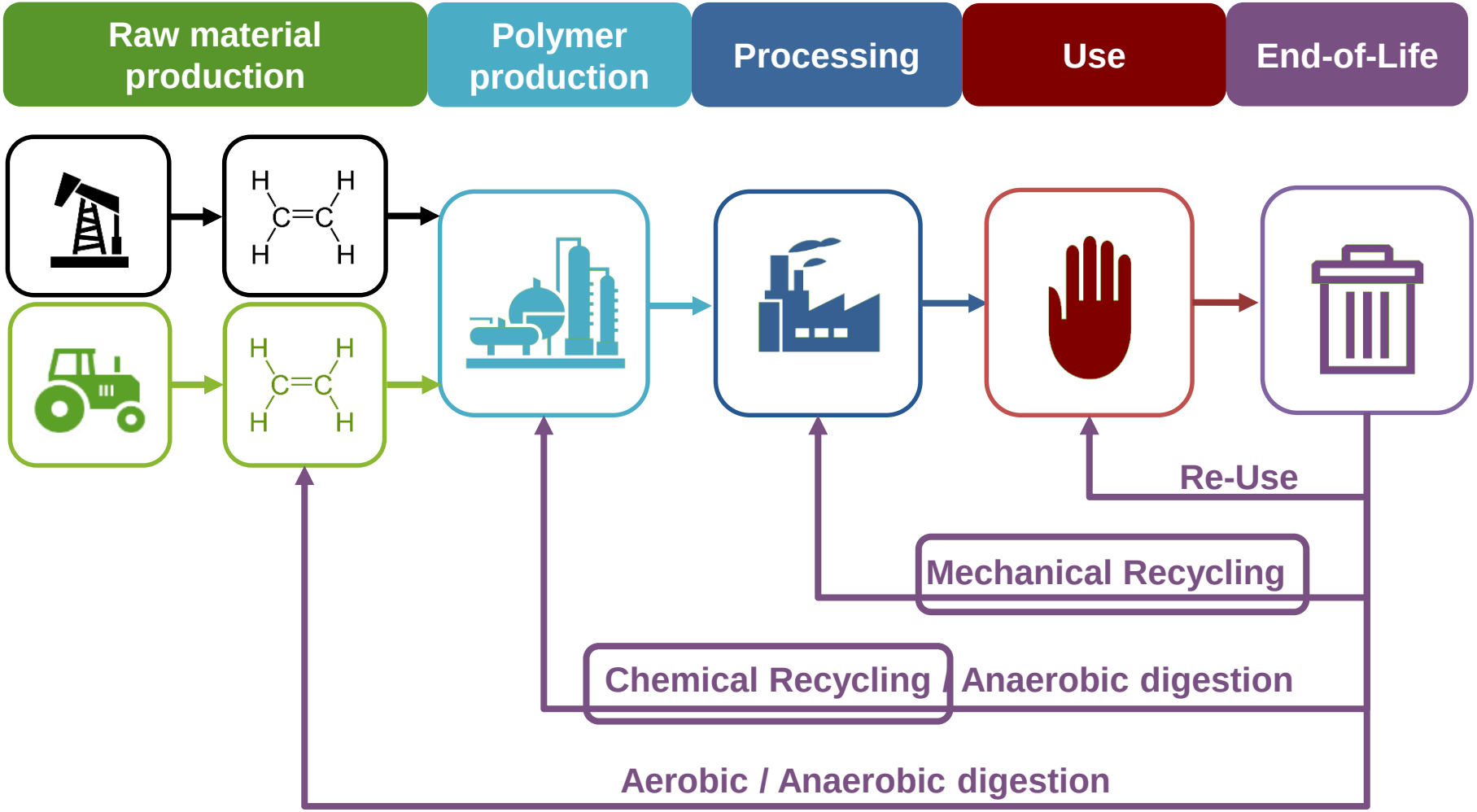
Agenda

1. End-of-Life options for Biopolymers and overview of (Bio-)polymer recycling
2. Recycling of pre-consumer waste
3. Recycling of post-consumer waste
4. Summary & Outlook

Biopolymer End-of-Life options



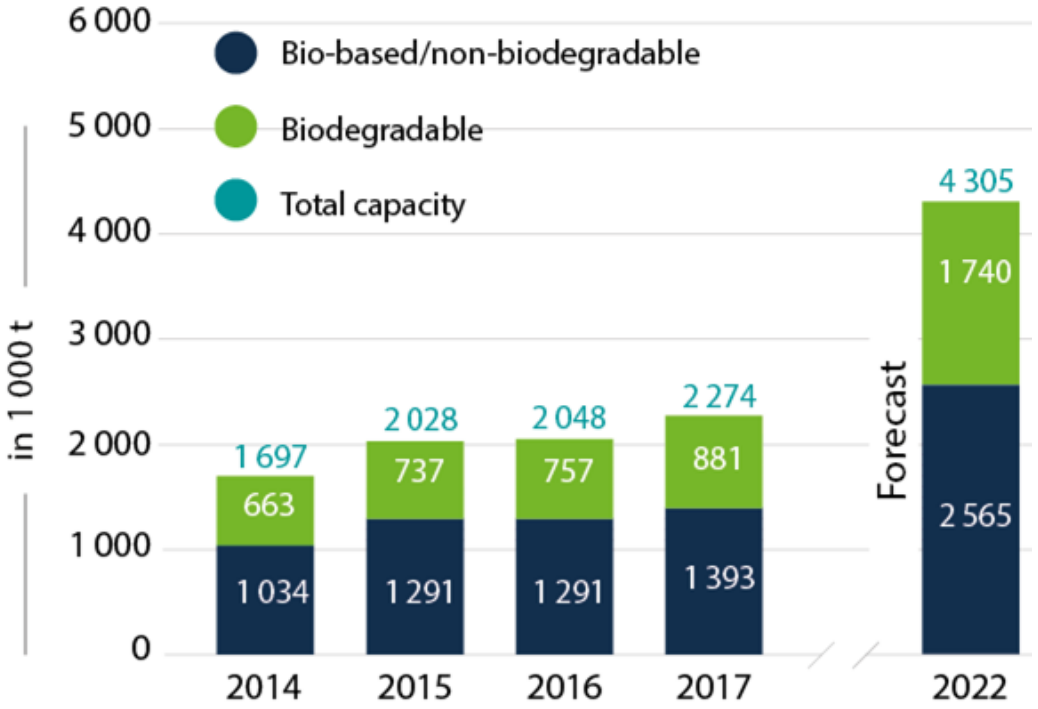
Biopolymer End-of-Life options



Motivation for recycling

- **Expected growth in demand** of biopolymers: 2017 → 2022: *CAGR* ~14%

- **Driving force:**
  biobased, non-degradable
  (e.g. Bio-PE, Bio-PET)

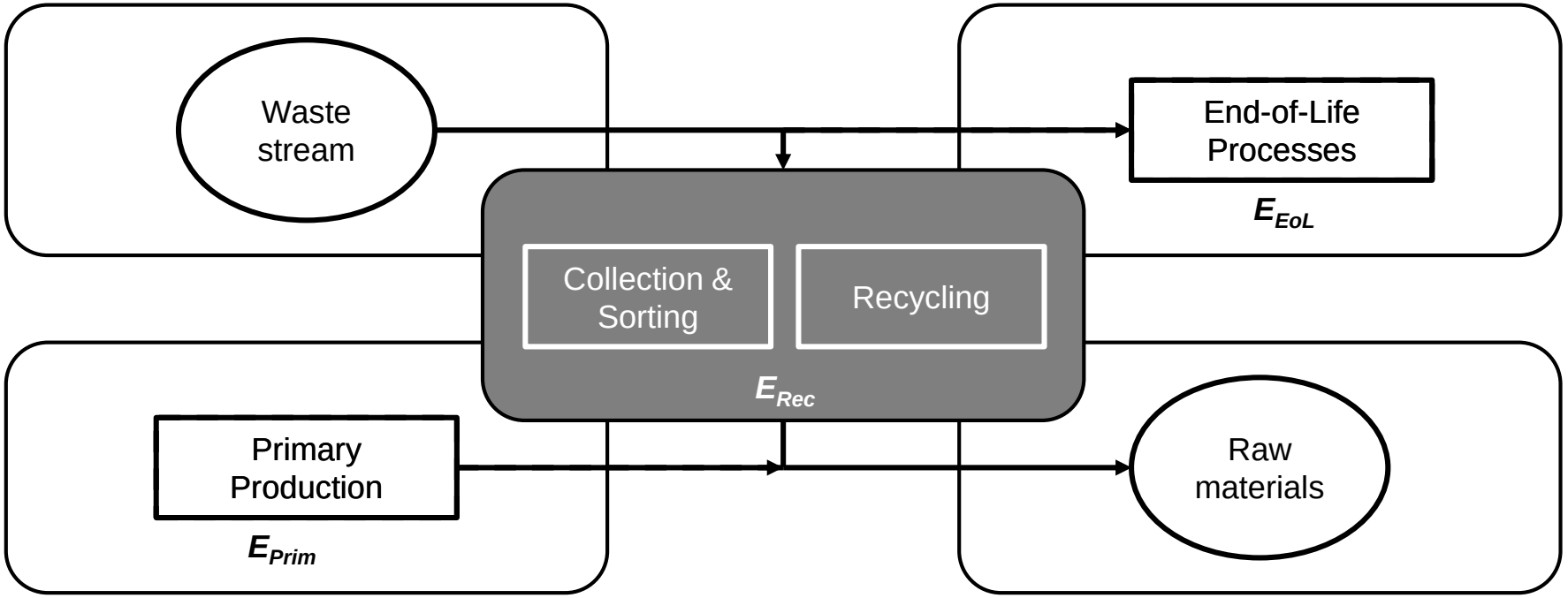


Source: IfBB

- **Non-degradable biopolymers need waste management like fossil-based polymers**

Motivation for recycling

- **Recycling can have positive economic and environmental impact**



$$E_{Rec} < E_{EoL} + E_{Prim}$$

Source: Geyer et al. (2016)

Waste streams: pre- and post-consumer

PRE – CONSUMER:

- **Source**: Manufacturing enterprises
- **Characteristics**:
  - Easy collection
  - Mono-material / homogeneous waste streams
  - Low contamination
  - “High quality”

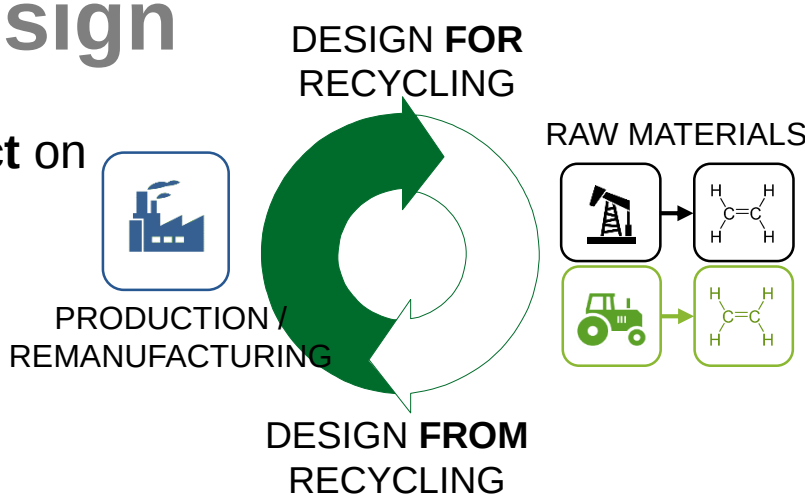
POST – CONSUMER:

- **Source**: Individual households, offices etc.
- **Characteristics**:
  - Multi-material waste stream (high dilution)
  - Contaminated with residues
  - “Low quality”

Source: IfBB, Rotorua lakes Council

Design and Recycling: Influence of packaging design

- Design of plastic products has a **large impact** on
  - Recyclability
  - Potential to incorporate recyclate



- Design **FOR** recycling:
  - Influencing factors for packaging:
    - Which color? – transparent, black, …
    - Which material?
    - Material composite? – multi-material design → separation?
    - Sleeve?
    - Type? – Bottle, film, blister, …

- Design **FROM** recycling:
  - Matchmaking between recycle characteristics and product requirements

(Bio-)Polymer recycling overview

Polymer recycling

Waste2Energy

- Waste combustion with energy production
- Waste as substitute fuel in cement industry
- …

- Material is lost

Mechanical

- Compounding of production-scrap (mono-material, pre-consumer)
- Collection, sorting, cleaning and compounding of mixed post-consumer waste

- Mechanical stress lowers material quality (downcycling)

Chemical

- Pyrolysis
- Solvolysis
- Gasification
- …

- Changes to molecular material structure occur

(Bio-)Polymer recycling overview

- **Scarce experience in the field of thermoplastic biopolymers**

- **Causality dilemma**:
  - Industrial scale recycling requires significant investments
  - Investment will only come if biopolymer commercial volumes and sales increase sufficiently
  - Uncertain recycling possibilities hinder demand for bioplastics and thus, prevent high quantity waste streams

- **To be expected**: Similar behavior (and problems) to conventional, fossil-based thermoplastics
- **Stronger downcycling-effect**
  → lower thermomechanical and chemical resistance

- **Current status**: No industrial recycling streams for biopolymers

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Mechanical recycling of pre-consumer PLA

PLA yoghurt cups

- Amorph PLA
- Used for Thermoforming

worksheet scrap from punching

- **Homogenous waste**
- Residues: adhesives & printed paper

Recyclate: PLA regranulate

- light green color

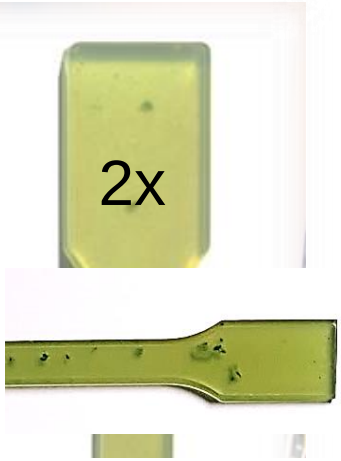
Source: IfBB

Mechanical recycling: Processing

Production scrap

feed → cutting mill → air separation → ground material

sieving



without the use of melt filter

with the use of melt filter

Extrusion → Regranulate

Analysis

Utilization of melt filter in the extrusion

Source: IfBB

Mechanical recycling of pre-consumer PLA - summary

- **PLA is generally suitable for mechanical recycling**
- Optimization of the recycling process regarding color and paper fraction can be achieved
- **No significant changes of mechanical properties**
- Substantial changes of processing properties (rheological characteristics)

- **Recycling of homogenous pre-consumer waste of PLA is feasible, similarly to the equivalent petrochemical materials**

- Possible application in short-lived products:
  - Gardening and landscaping sector
  - Packaging and transport sector

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Post-consumer polymers: sorting

- Post-consumer (bio-)polymers pass extensive automated and/or manual sorting processes in specialized **M**aterial **R**ecovery **F**acilites (MRF)

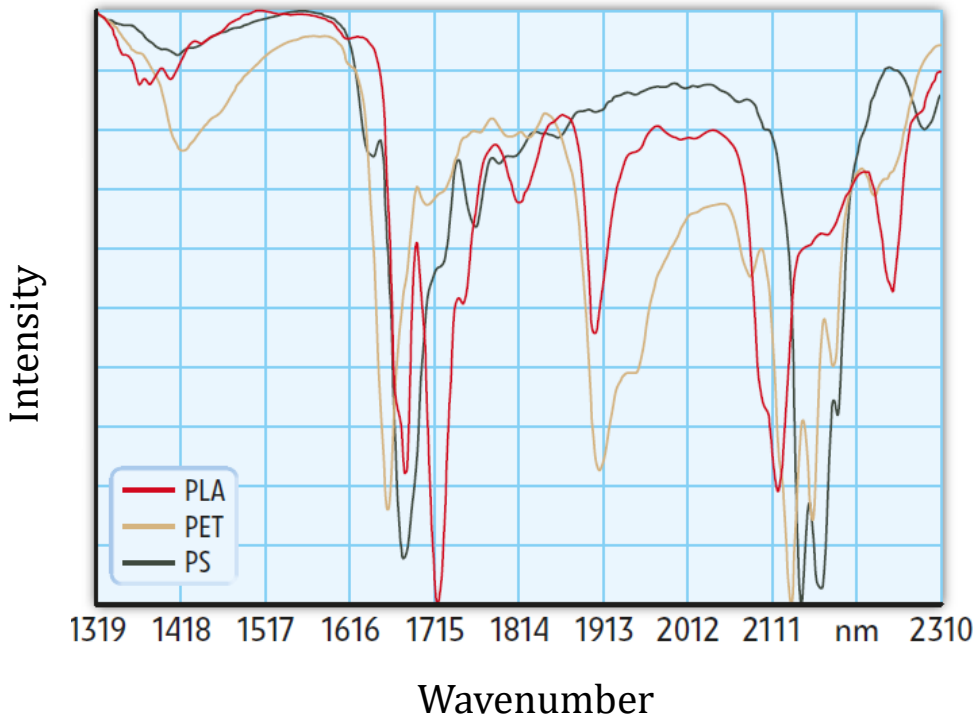
- Sorting processes include:
  1) Spiral wave separation
  2) Ballistic separation
  3) Air separation
  4) Metal separation
  5) Eddy current separation (non-ferric metals)
  6) NIR separation
  7) Manual sorting

Source: Lobbe Entsorung West Gmbh; Unisort

- Currently **PP, PE, PET, PS** are recovered, rest makes up mixed plastics

Post-consumer polymers: sorting

- **Existing NIR sorting systems can be adapted to identify and separate biopolymers, e.g. PLA**



Source: Unisort; Siebert, Schlummer, Mäurer (2016) Kunststoffe 7/2016; p. 80

Post-consumer polymers: Chemical recycling

CreaSolv® Process

- **Basic idea**: PLA recycling by selective dissolution from mixed waste streams
- **Process steps:**
  1. Shredding
  2. Dissolution
  3. Filtration
  4. Precipation
  5. Drying
  6. Extrusion
- **Current status:**
  - Technically feasible
  - Recovery of high-quality and pure PLA recyclates
  - Upscaling successful

SOLVOPET®

- **Basic idea**: Depolymerization of PET by using Solvolysis → recovery of PTA & MEG
- **Process steps**:
  1. Shredding
  2. PET Depolymerisation
  3. Drying
  4. Dissolution
  5. Filtration & Purification
  6. PTA Precipation
- **Current status:**
  - Continuous depolymerization patented
  - Upscaling from lab-scale to pilot plant scale ongoing

Source: CreaSolv; RITTEC & ICTV

Post-consumer biopolymer recycling Summary

- Biopolymer drop-ins could be recycled together with fossil-based counterparts
- Cross-contamination of petrochemical polymers with biopolymers (e.g. PET with PLA) is problematic, but is only a problem of sorting technology
- Development of chemical recycling processes is ongoing

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Summary and outlook

- Most disposal options, except for composting, are not examined sufficiently for biopolymers → **Uncertain recycling landscape for biopolymers**
- Biopolymers expected to behave similar to conventional polymers
- Mechanical recycling of pre-consumer waste is possible and feasible
- Chemical recycling of post-consumer waste is under development
- Currently there is no industrial recycling path for post-consumer biopolymers, they end up in the mixed polymer fraction
- **Recycling of biopolymers should be based on existing waste collection systems**

Recycling of Biopolymers – thank you!

Technische Universität Braunschweig
Institute of Machine Tools and Production Technology
Sustainable Manufacturing & Life Cycle Engineering

Julian Rickert
Life Cycle Engineering research group

- Life Cycle Assessment and Engineering:

  Development of methods and tools to support decision making for recycling

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