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STAR ProBio

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Techno-economic sustainability criteria and indicators for End-of-Life options of bio-based plastics

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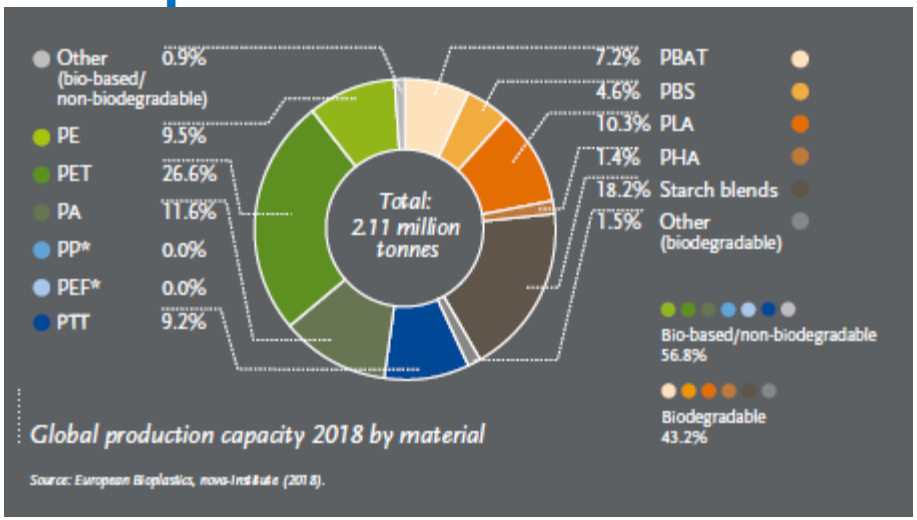
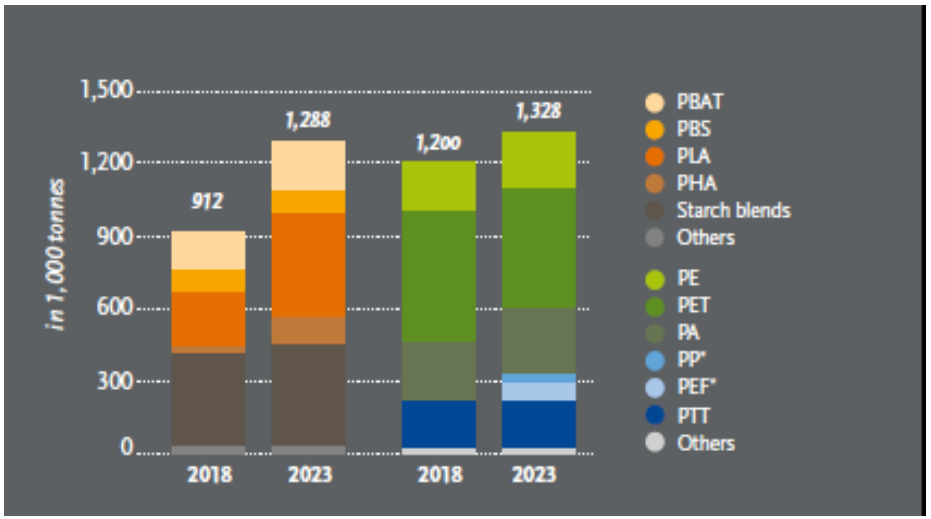
Bio-based plastics

- **Bio-based plastics global production capacity in 2018 and predicted for 2028 :** [1]





Bio-based plastics market:

- From 2.1 mt (2018) to 2.6 mt (2023)

Bio-based non-biodegradable polymers: 56.8%

Bio-based biodegradable polymers: 43.2%

[1] European Bioplastics, BIOPLASTICS - facts and figures

1. Sustainable bioeconomy

- **Circular economy:** [1]
  - Circular system **resource inputs and outputs are minimized** through the design for recirculation and long lasting loops of reuse following repair, remanufacturing and refurbishing and also recycling, and upcycling
- **Bioeconomy:**
  - **Renewable resources of biological origin**
  - The processing methods used in **biorefineries** aim at valorising the biomass as resource for the production of bioenergy and bio-based materials
- **Sustainable bioeconomy :** [2]
  - The **renewable segment** of the circular economy
  - The **sustainable circular bioeconomy** turns biogenic **waste and residues** into renewable resources for the production of added value bio-based materials

1 Zuin, V.G. & Ramin, L.Z. Top Curr Chem (Z) (2018) 376: 3. https://doi.org/10.1007/s41061-017-0182-z

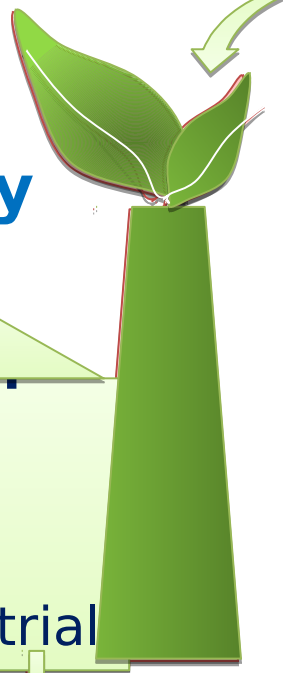
2 [1] European Commission, A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment, Updated Bioeconomy Strategy, 2018, doi:10.2777/792130

Recirculation and alternative end-of-use/ life routes of

sustainable circular bioeconomy

based products

- **Reuse**
- **Recovery**



Recovered bio-based materials = New bio-based raw materials

Recirculation into the production system or through industrial symbiosis

By-products, Post-

Products, market, Post-consumer

Bio… EoL recovery routes hierarchy:

a) Material recovery:
- **Mechanical recycling**
- **Chemical or feedstock recycling**

b) Organic recycling
- **Aerobic composting**
- **Anaerobic digestion**

c) Energy recovery

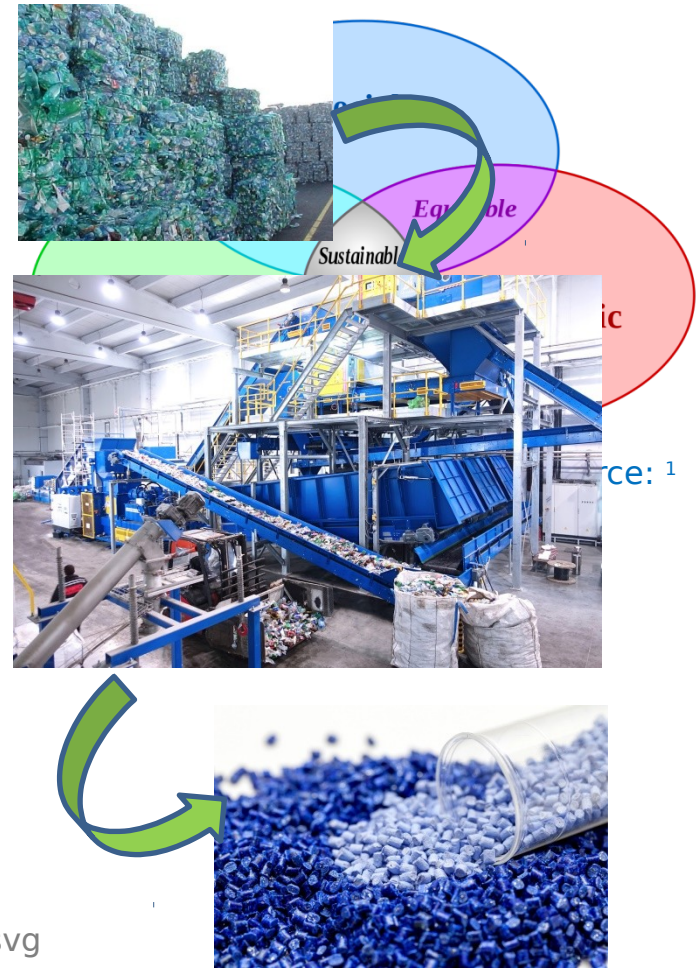
The Circular Economy Package (EC) sets new EU recovery targets by 2030:

Recycling: 65% of municipal waste; **75%** of packaging waste;

Lanfilling: Binding max **10%** of municipal waste; **Ban** landfilling of separately

2. Techno-economic sustainability methodology for material recovery of post-consumer bio-based plastics

- **Techno-economic sustainability criteria:**
  - Criteria to assure the feasibility and viability of mechanical and chemical recycling of post-consumer bio-based plastics
- **Environmental and social sustainability criteria are not considered in this work**
  - They need to be included to complete the sustainability assessment of any EoL option
- **Boundaries: gate to gate**
  - Entrance to the facility: sorted post-consumer and post-industrial bio-based plastics
  - Exit from the facility: final recovered material



ce: [1]

[1] https://commons.wikimedia.org/wiki/File:Sustainable_development.svg

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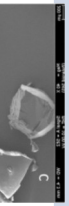
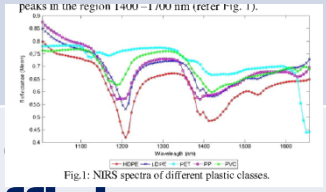
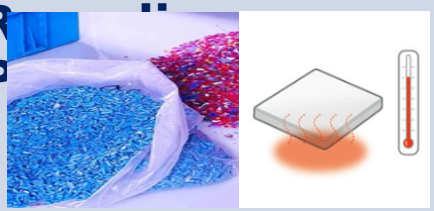
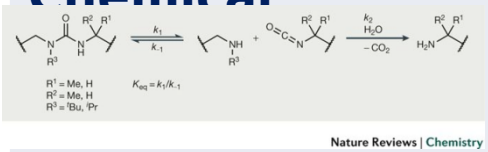
Criterion 1: Technical feasibility based on existing processes and possible improvements

Technical feasibility Components	Material recovery of post-consumer / post-industrial bio-based plastics
Biodegradability  https://doi.org/10.1016/j.polymdegradstab.2017.12.011  Fig.1: NIRS spectra of different plastic classes.	➢ Bio-based equivalents to conventional polymers: follow recycling streams of the corresponding conventional plastics – Non-recyclable non-biodegradable plastics: routed to energy recovery in the form of SRF ➢ Biodegradable plastics: limitations apply when these materials are to be treated by mechanical or chemical recycling – Non-recyclable biodegradable plastics: organic recycling
S… efficiency	➢ If collected separately into mono-streams or sorting efficiency is high: – mechanical recycling becomes the most attractive EoL option – chemical depolymerization recovers high…

Criterion 1: Technical feasibility based on existing processes and possible improvements

Technical feasibility Components	Material recovery / organic recycling of post-consumer / post-industrial bio-based plastics
Mechanical R… P… 	➢ Thermal stability: – first prerequisite for any polymer ➢ Contamination by non-compatible polymers: – processing problems and degraded quality of recyclate ➢ Physical limiting factors: – presence of contaminants, degradation etc.
Chemical  doi.org/10.1038/s41570-017-0046	➢ Efficiency of depolymerisation process: – high recovery rates of high quality monomers/chemicals is crucial ➢ A low efficiency process needs improvements : – design and production of innovative depolymerization catalysts – development of chemically recyclable polymers, etc.
Compostability	➢ Conformity to standard specifications for industrial

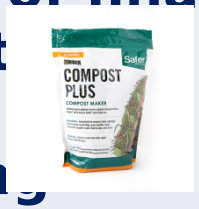
Criterion 2: Economic viability based on existing processes

Economic viability Components	Material recovery / organic recycling of post-consumer / post-industrial bio-based plastics
Infrastructures for materials rec   **plastic waste**	➢ Availability and/or distance of available infrastructures: – Mechanical recycling is the first priority alternative EoL route or not – Chemical recycling becomes a valuable alternative recycling route in the near future – Requires support by research & development activities – Organic recycling and/or AD suitable EoL options depend on infrastuctures
A l	➢ Economic viability depends on: – constant supply of bio-based plastics – sufficient quantities – commercial mono streams of bio-based plastics – operate near their maximum design capacity

Criterion 2: Economic viability based on existing processes

Economic viability Components	Material recovery / organic recycling of post-consumer / post-industrial bio-based plastics
Recovered 	➢ Degradation characteristics of recyclates of conventional and bio-based non-biodegradable plastics : – defined by relevant standards ➢ Biodegradable bio-based plastic recyclates: – no standards exist
Rec d ma qua chemical ISO **ISO 15270:2008**	➢ The feedstock nature affects the economic feasibility of the chemical recycling processes – Pure polymer streams result in high value products by chemical depolymerisation processes (original monomers recovery) – Thermochemical recycling processes, usually end up in products characterized by low quality (mixtures of various hydrocarbons)
Organic	➢ The organic recycling final products quality:

Criterion 2: Economic viability based on existing processes

Economic viability Components	Material recovery of post-consumer / post-industrial bio-based plastics
Market of re… b… …ls  	➢ Market price for a specific quality of recovered bio-based materials: – Not economically viable if the prices obtained for specific quality of recovered materials do not support its operation
Market of final product… organic recycling 	➢ Availability of markets for organic recycling end-products: – shift from composting to AD or to combined AD and composting treatments because of lower gate fees to biowaste operators – biowaste operators are forced to generate revenue through other options (e.g. sales of electricity from biogas production)

Criterion 2: Economic viability based on existing processes

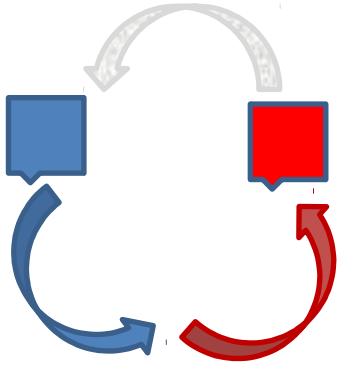
Economic viability Components	Material recovery of post-consumer / post-industrial bio-based plastics
Estimated fi f  https://www.rathandeep.com/case-study-importance-financial-feasibility/	➢ Based on economic data describing the profitability of the processes: – existence of is very limited for bio-based post-consumer products – mechanical recycling: extrapolation from available data for conventional plastics – chemical recycling: no data are available even for conventional plastics (processes have not been commercialized yet) – organic recycling: data available for composting and AD of biowaste directly applicable for bio-based products (except for the gate fee)

Criterion 3: Common environmental and techno-economic criteria of material recovery

	Material recovery / organic recycling of post-consumer / post-industrial bio-based plastics
Material mass recovery efficiency	
Additives impact on sustainability of materials recovery / organic recycling	 htt rg/design-guidelines
Resources utilization efficiency	
Waste – Emissions	

4. Techno-economically sound recirculation potential of recycled post-consumer /post-industrial bio-based products through alternative EoL routes

- A gap exists between **product design, materials supply, marketing and manufacturing** and **the return flow of recycled/ recovered materials**
- This fragmentation has been recognized as a **major missing link in the circular economy** [1]
- In an effort to integrate the fragmented cycle and allow for the circular economy to develop, new rules have been proposed by the European Commission including *"more closely harmonised rules on the use of extended producer responsibility (EPR)"*



[1] European Commission, A European Strategy for Plastics in a Circular Economy, Communication from the Commission to the EP&C, the European Economic and Social Committee and the Committee of the Regions Brussels, COM(2018) 28 final

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TESA Criteria for recirculation and alternative end-of-use/ life routes of bio-based products

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