Biopolymers for Photovoltaics?

General framework, suitability and challenges

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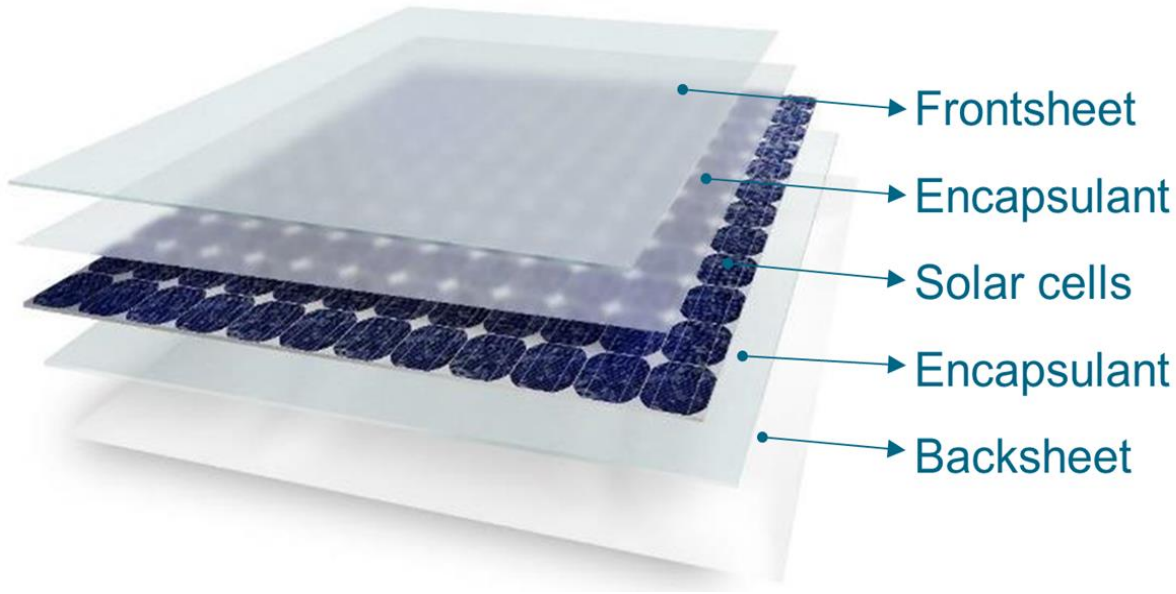
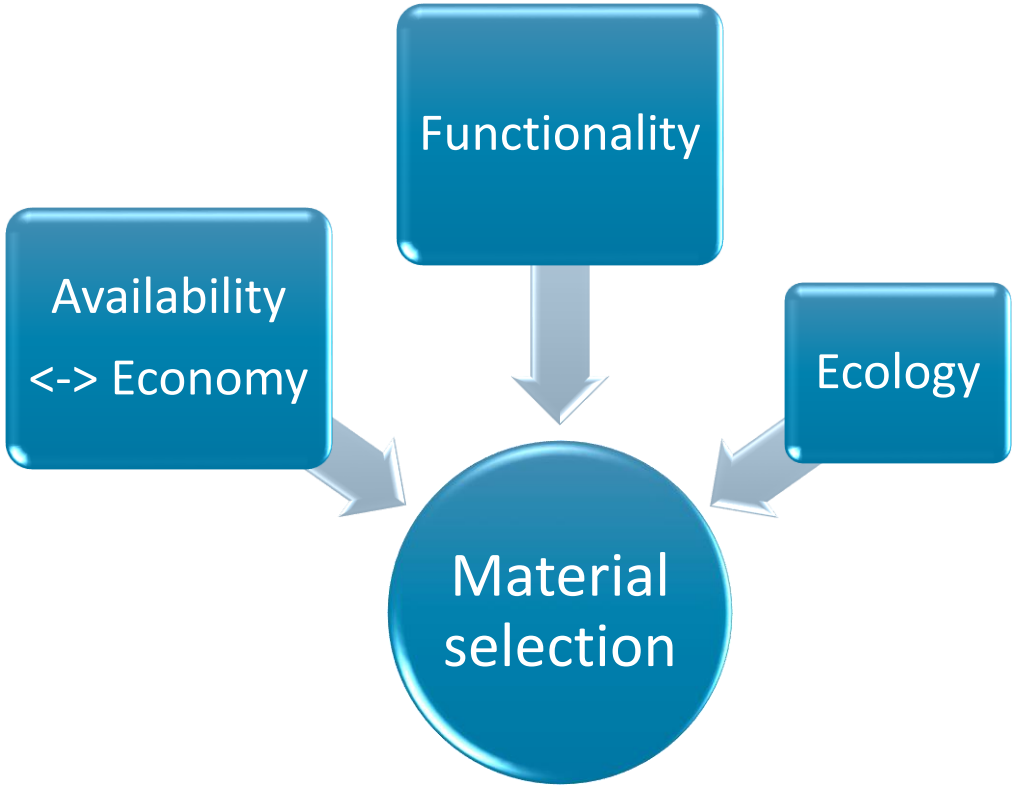
Polymers in PV-Moduls





Polymers used in

- Front sheet: ETFE, PET
- Encapsulant: EVA, PE, polyethylene copolymers
- Backsheet: PET, PVF, PVDF, PP …
- Junction box: PC, PC-ABS,….

Pros for Biopolymer

“In general, attempts to create something less harmful and more friendly to the environment than traditional plastics are on the way for more than 30 years. Formally, such plastics exist. There is a European standard EN 13432 “

- *New feedstock source -> avoiding fossil resources (fossils are faster used than produced -> decreasing availability)*
- *Lower contribution to global carbon footprint than petrochemical-based polymers*
- *New material properties*
- *Diverse disposal options -> bio-degradable and bio-compostable*

Degradability of biopolymers

Biodegradable polymers differ from other plastics by possibility to decompose in the environment under the influence of

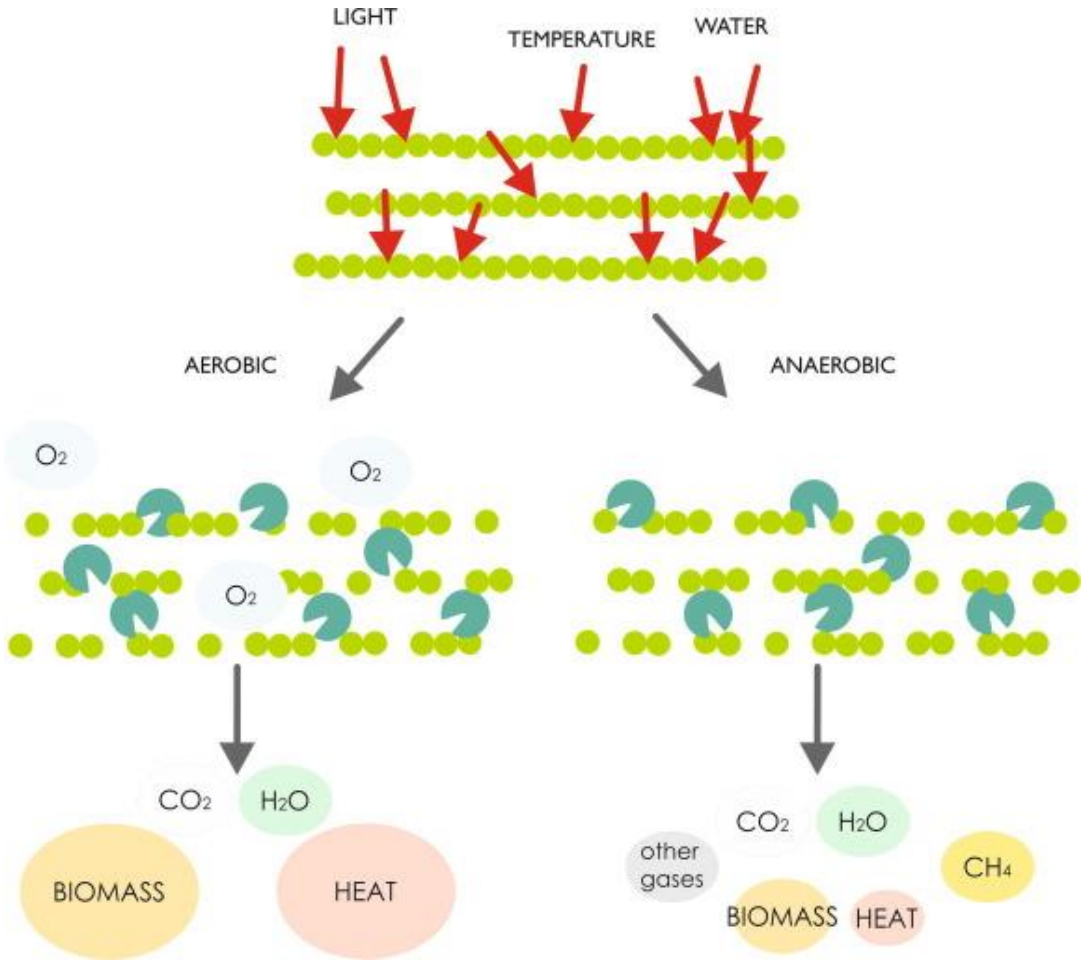
- ***microorganisms and***
- ***physical factors (UV radiation, temperature, …)***

Long chains of polymer molecules break down into carbon dioxide and water, as well as methane, biomass and inorganic compounds.

Microbiological degradation of synthetic biopolymers takes place through the action of

- ***enzymes and***
- ***acids and peroxides secretes from bacteria,***
- ***fungi,***
- ***yeast, etc.***

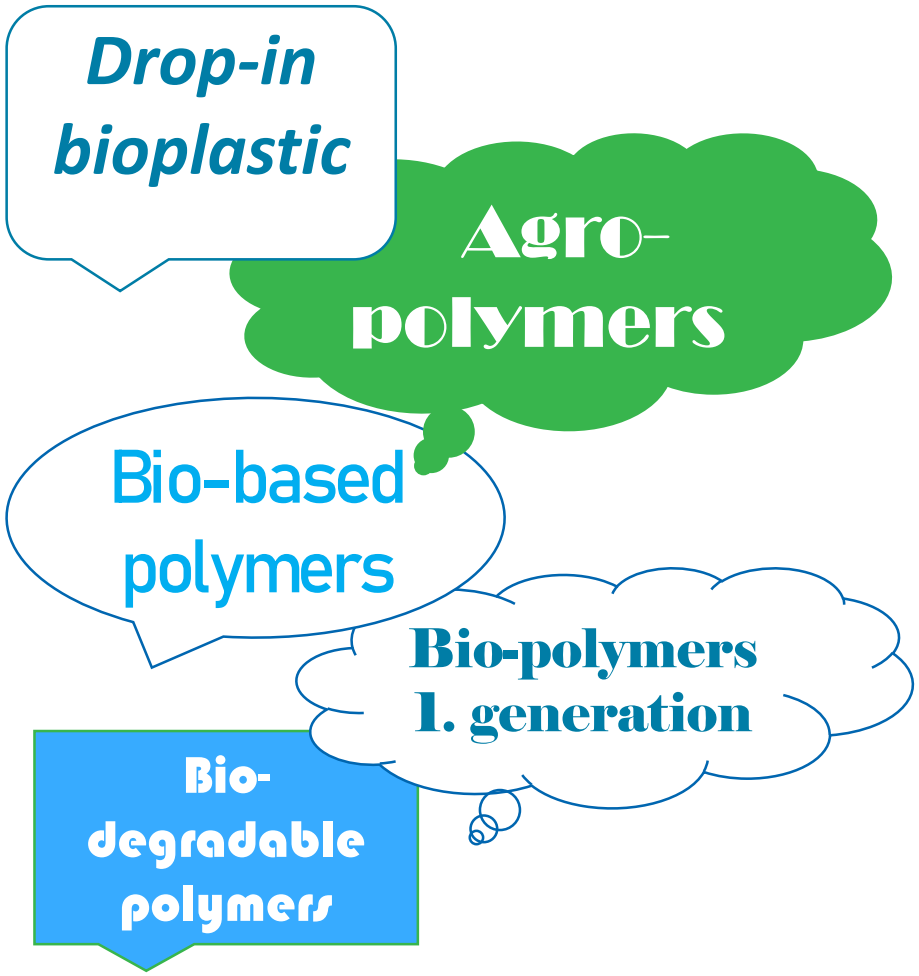
Interesting for packaging materials, but not preferable for PV

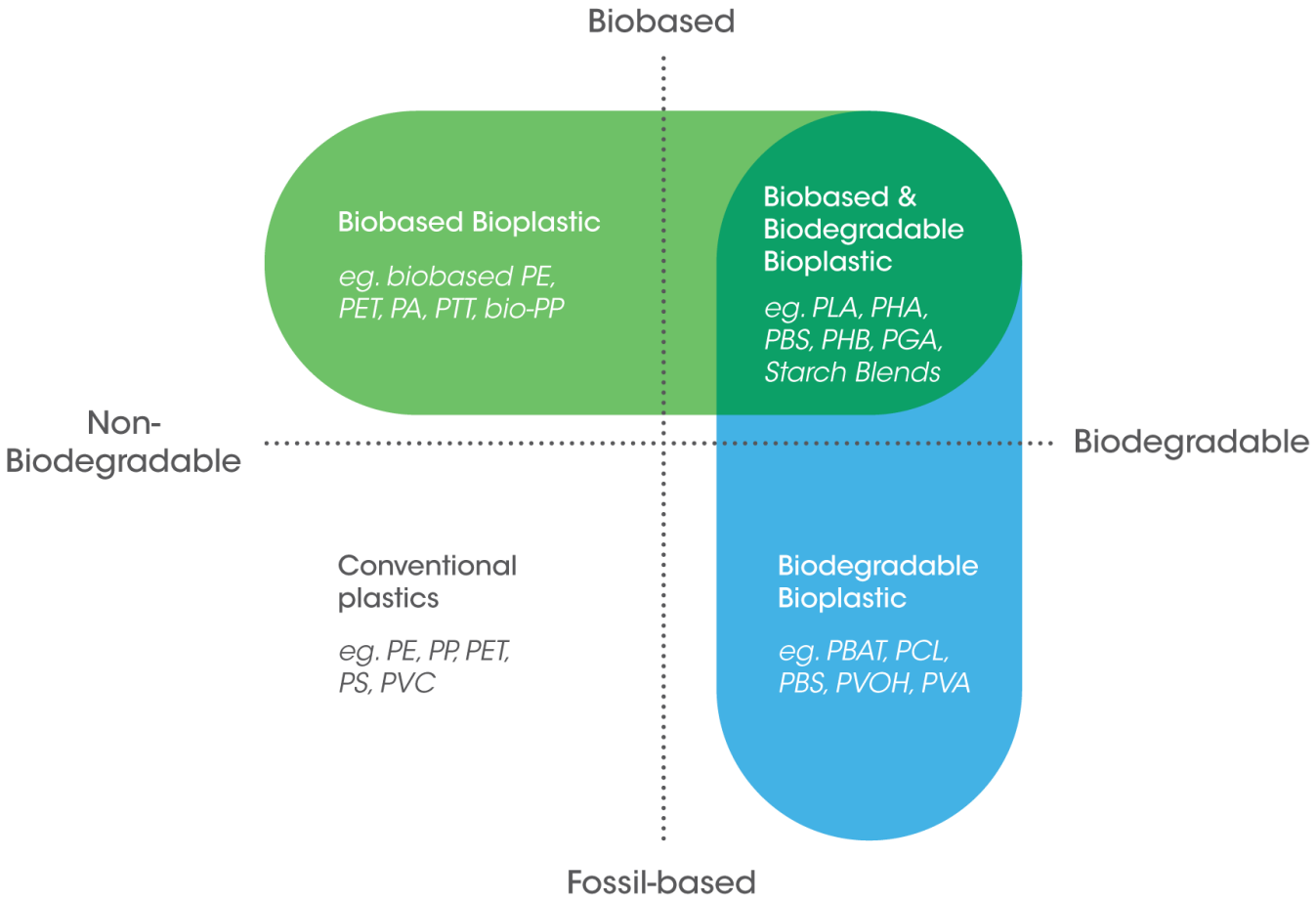


Veronika Bátori, Dan Åkesson, Akram Zamani, Mohammad J. Taherzadeh, Ilona Sárvári Horváth, Anaerobic degradation of bioplastics: A review, Waste Management, Volume 80, 2018, Pages 406-413, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2018.09.040.

Definition: Biopolymers

„**Biopolymers** are natural polymers produced by the cells of living organisms"
"**Bioplastics** are plastic materials produced from renewable biomass sources"





https://www.tainstruments.com/material-analysis-for-bioplastics-quality-assurance-and-degradation/

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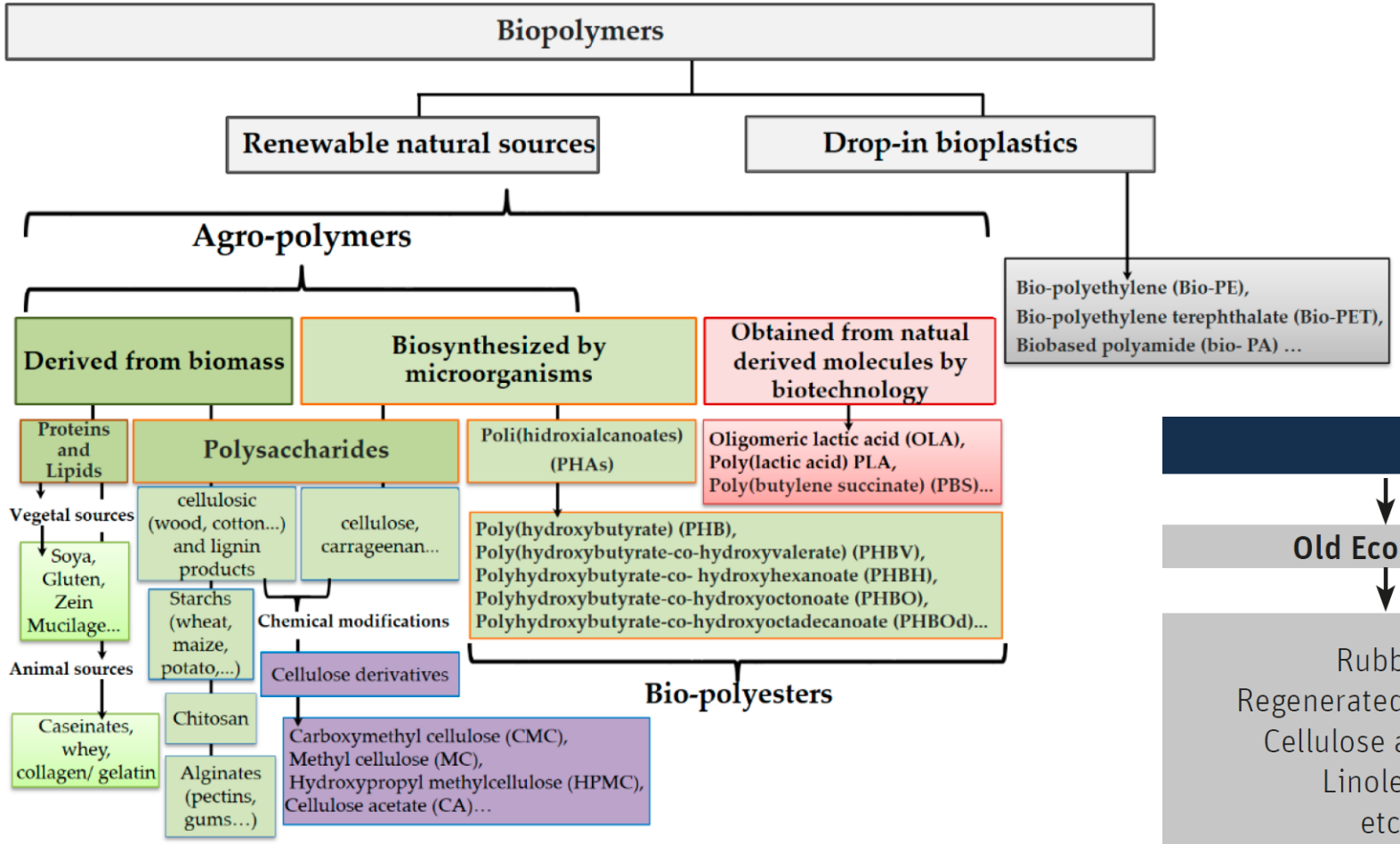
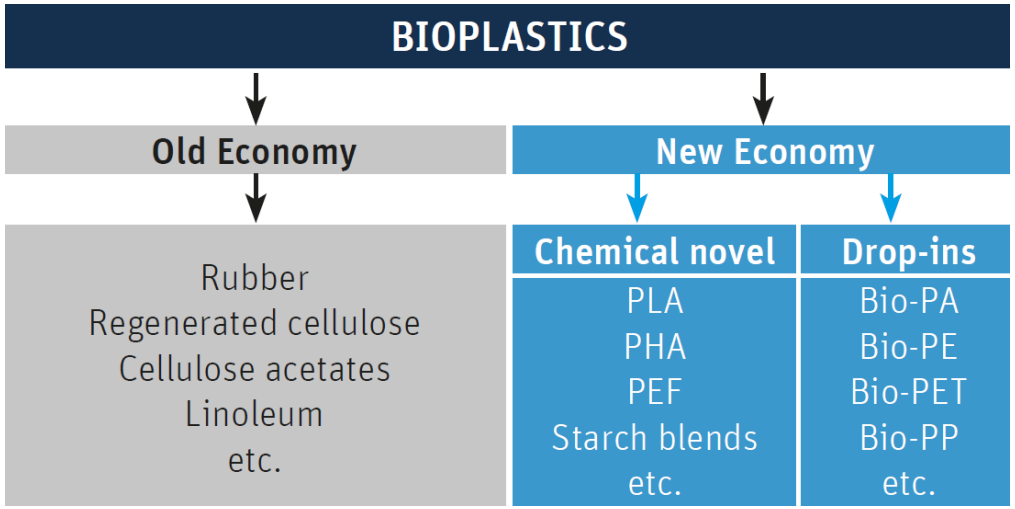
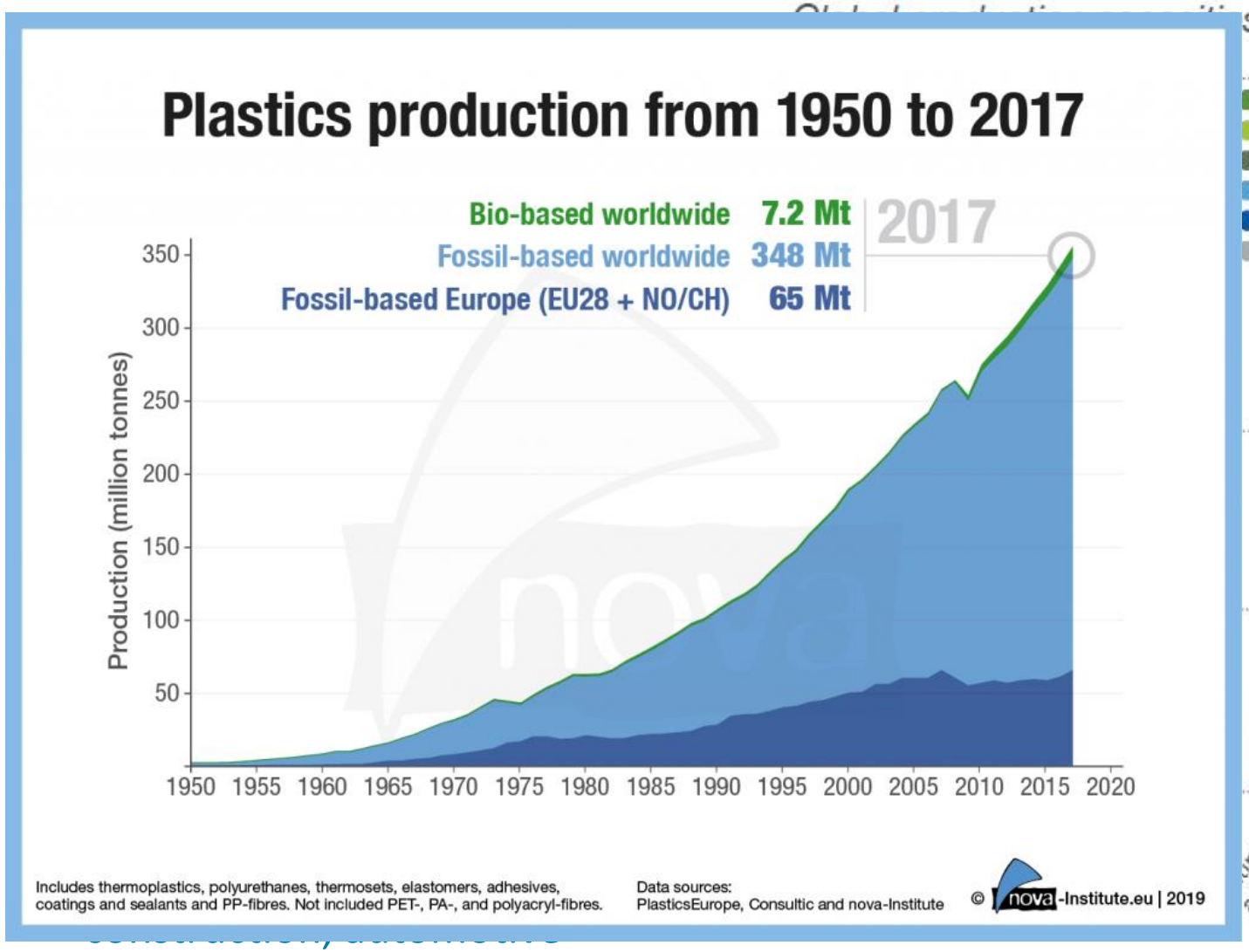
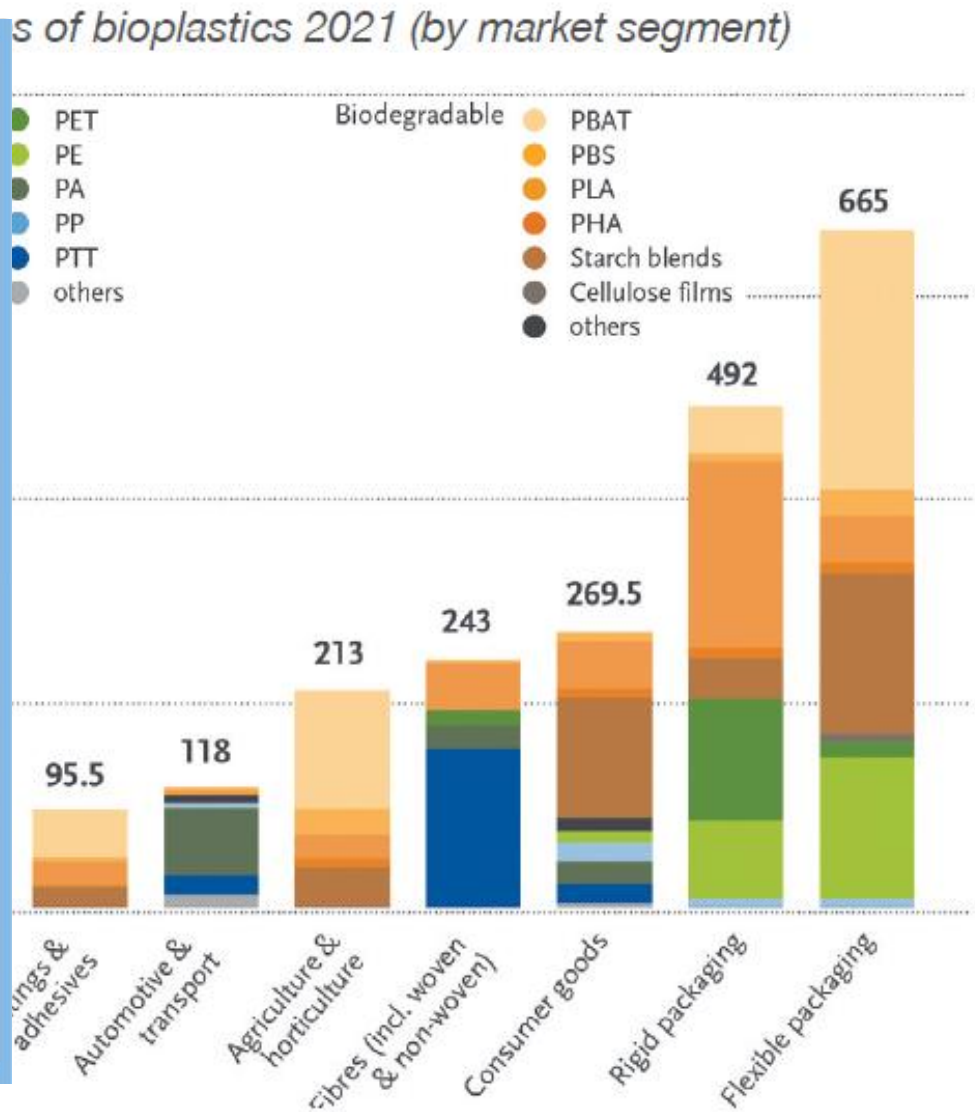




Balart, R.; Garcia-Garcia, D.; Fombuena, V.; Quiles-Carrillo, L.; Arrieta, M.P. Biopolymers from Natural Resources. Polymers 2021, 13, 2532. https://doi.org/10.3390/polym1315253

Biopolymers production capacities and application

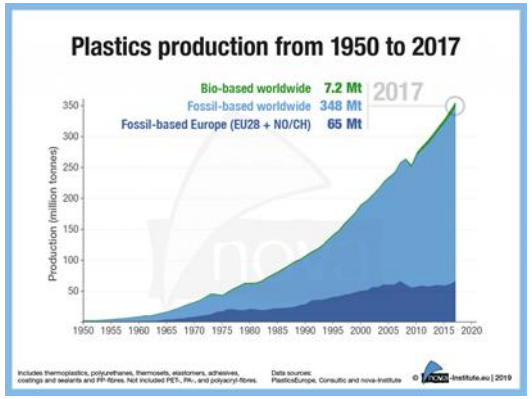




https://docs.european_bioplastics.org/publications/market_data/Report_Bioplastics_Market_Data_2021_short_version.pdf

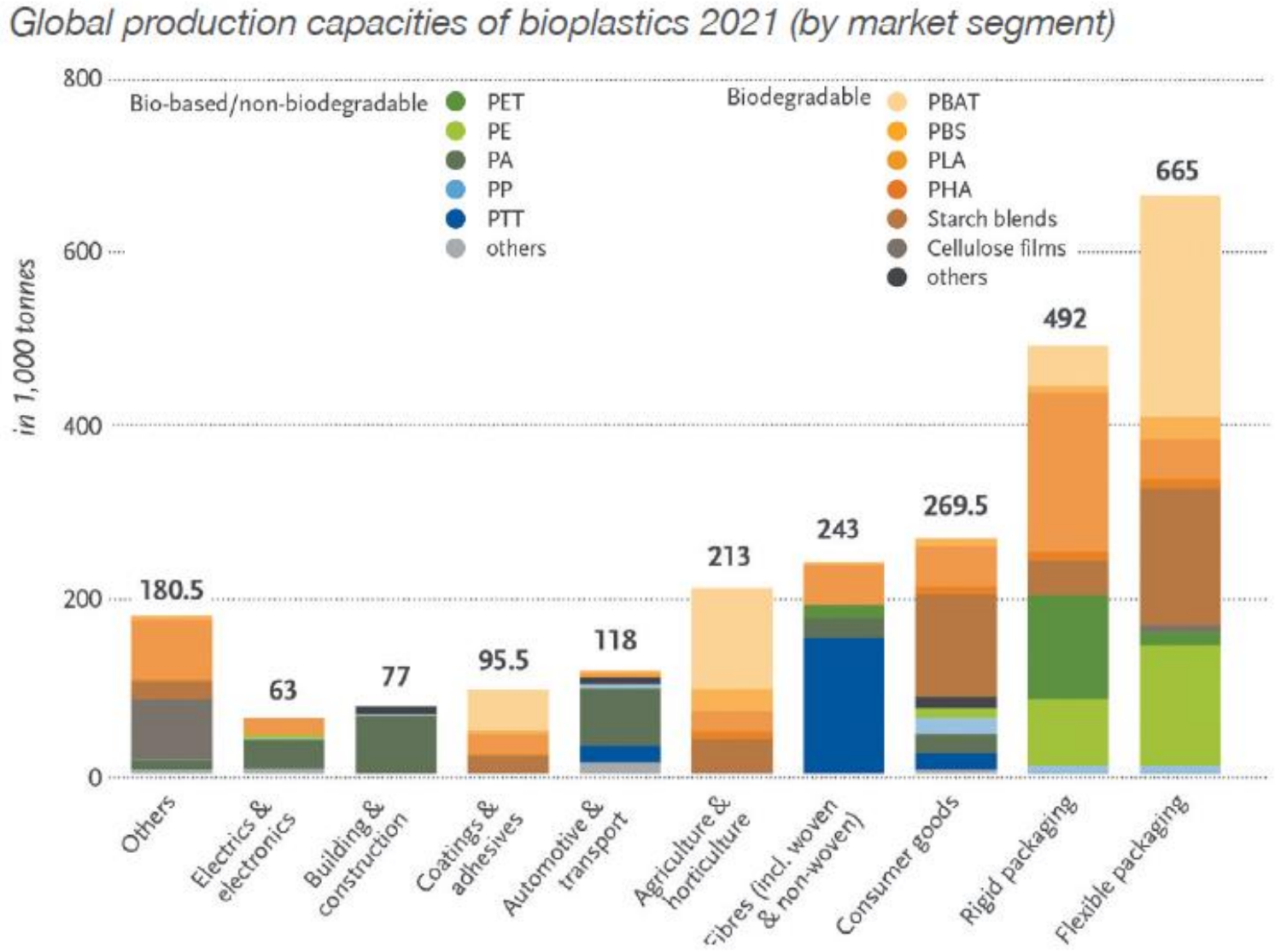
Biopolymers production capacities and application

- Currently bioplastics account for approximately 1 % of 335 million tons of plastics produced annually



- One third is dedicated to rigid and flexible packaging

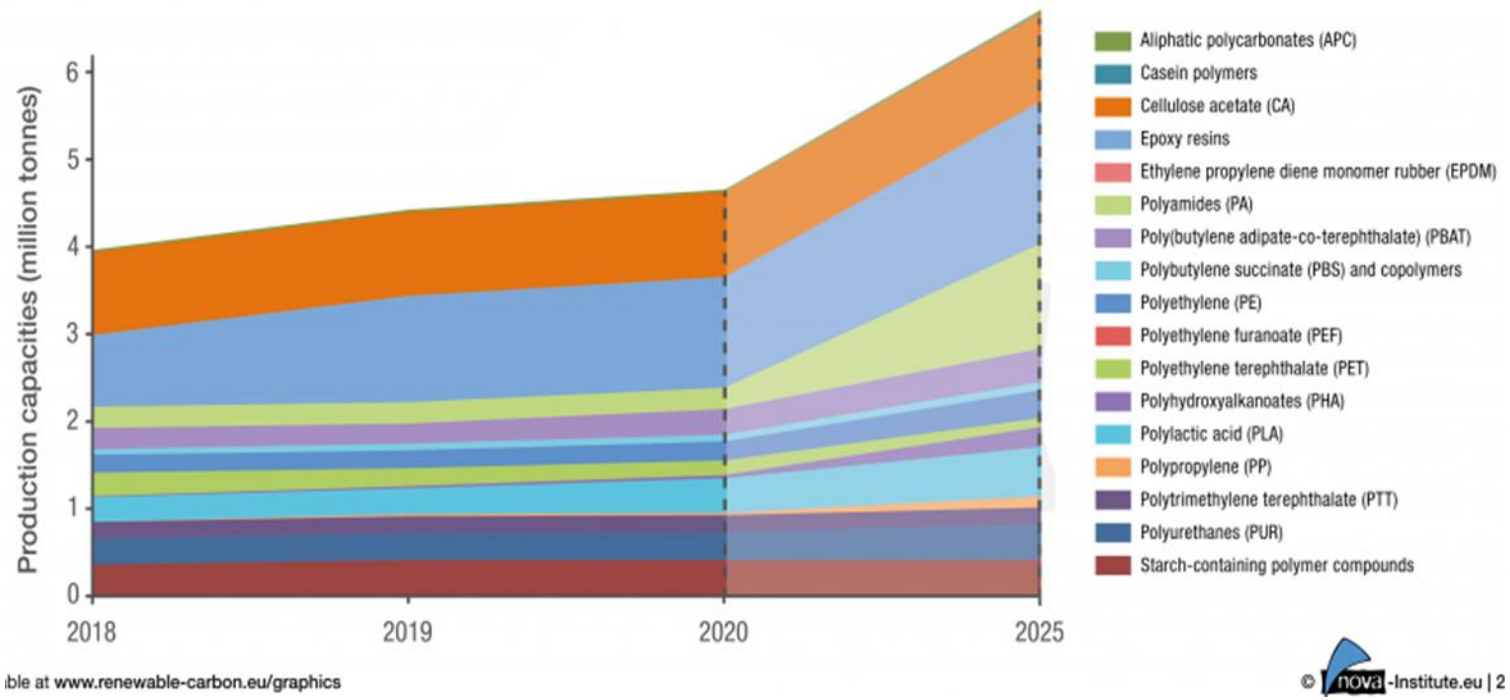
- Less use in electronics, construction, automotive



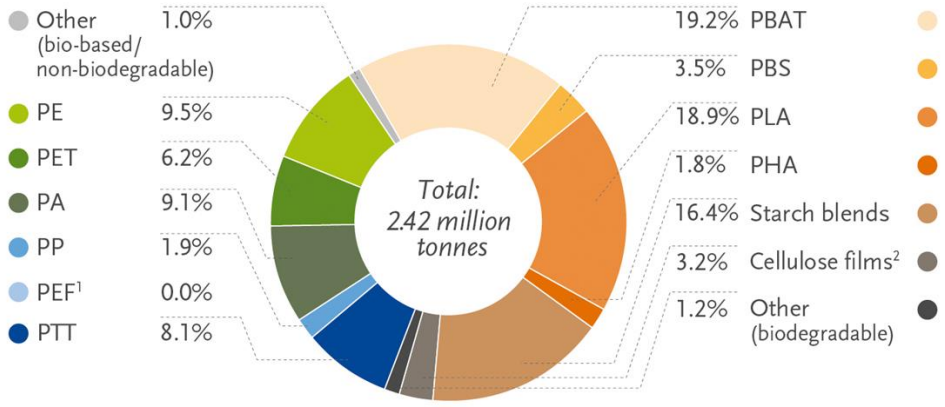
https://docs.european-bioplastics.org/publications/market_data/Report_Bioplastics_Market_Data_2021_short_version.pdf

Biopolymer production capacities

Bio-based polymers
Evolution of worldwide production capacities from 2018 to 2025



Global production capacities of bioplastics 2021 (by material type)



[1]PEF is currently in development and predicted to be available at commercial scale in 2023. [2] Regenerated cellulose films

Source: European Bioplastics, nova-Institute (2021)
*More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets***

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Are biopolymers feasible for use in PV modules? Which biopolymers would meet the requirements?

Bio4Sun - Biogenic plastics for solar technology applications

"This project aims at evaluating and testing the potential and application of biogenic polymers, i.e. polymers based on renewable resources and/or biodegradable polymers, for the use as components of photovoltaic or solar thermal devices."

Project Bio4Sun

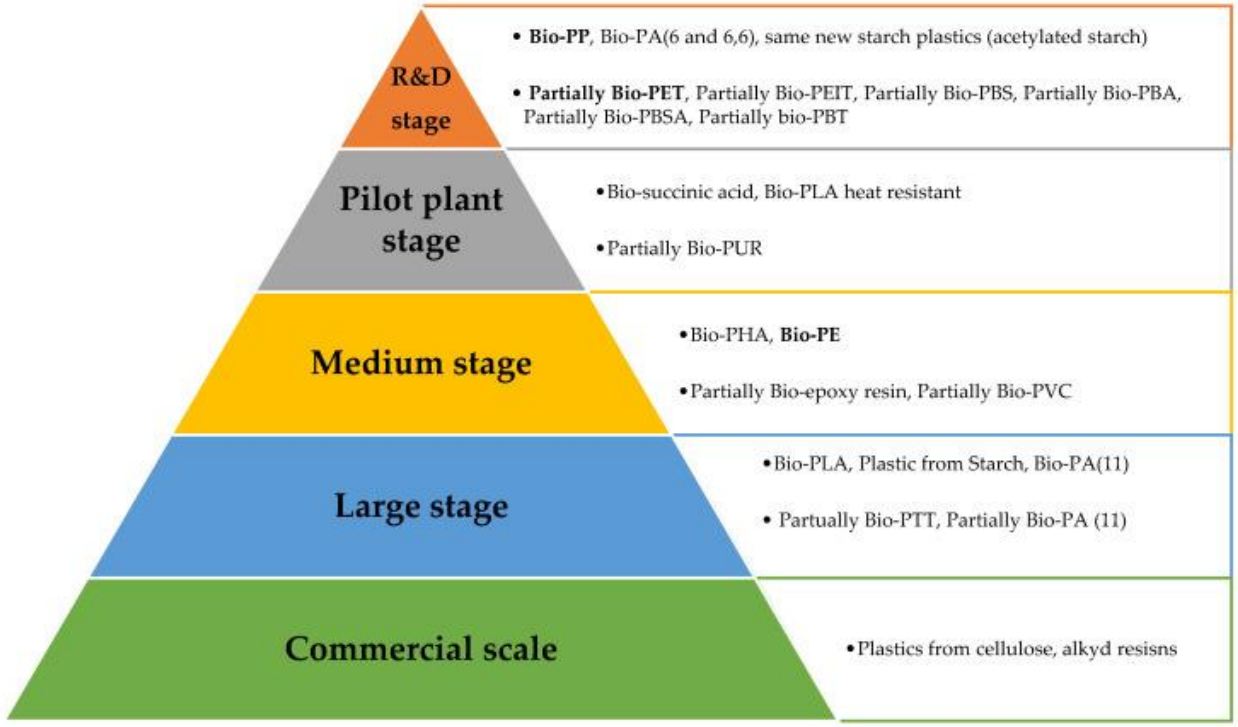
powered by klima+ energie fonds

Duration: 04/2013 - 07/2014

Consortium:

- *Montanuniversität Leoben - Chair for Material Science and Testing of Polymers*
- *Polymer Competence Center Leoben*

Funding: Klima- & Energiefond



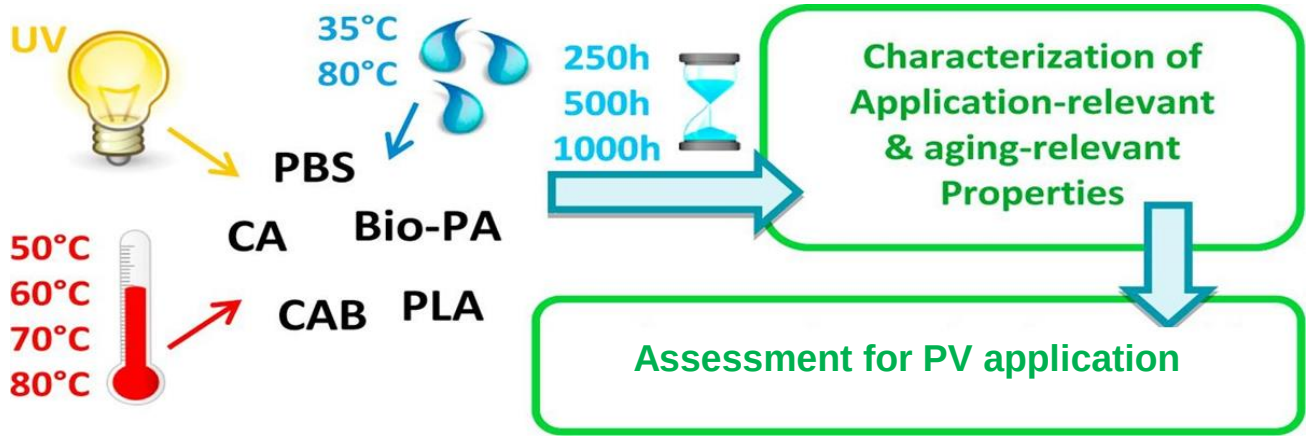
Siracusa V, Blanco I. Bio-Polyethylene (Bio-PE), Bio-Polypropylene (Bio-PP) and Bio-Poly(ethylene terephthalate) (Bio-PET): Recent Developments in Bio-Based Polymers Analogous to Petroleum-Derived Ones for Packaging and Engineering Applications. Polymers (Basel). 2020;12(8):1641. Published 2020 Jul 23. doi:10.3390/polym12081641

Investigation of Biopolymers for PV application

- **25 materials were selected and processed into films using flat film extrusion processes**

- The following material classes were investigated:

  - *Polylactic acid and polylactic acid blends*
  - *Cellulose polymers*
  - *Biopolyethylenes*
  - *Polyhydroxyalkanoates*
  - *Bio-thermoplastic elastomers*
  - *Bio-polyamides*
  - *Bio-Polyester*



Requirements to the material for application:

- *Processability by extrusion*
- *Application temperature range (-20°C - to 80 or 100°C)*
- *Mechanical properties*
- *Transparency*

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Biopolymers selection

- PBS, PHA2, PHA+Polyester, PP-W, TPA, TPC and the PBS/PSAC/PLA-blend do not exhibit a satisfactory service temperature range are excluded from further investigation.
- Mechanical constraints furthermore exclude the PE-LLD/PE-HD blend and the PE-LLD/PE-LD blend, all PHAs and their blends and Polyester W. The constraint of processability excludes the PLA/PMMA-blend and PHB from extended research
- 11 biopolymers were selected and subjected to aging procedures (thermal, hydrolytic, UV)
- Determination of the thermal, thermo-mechanical, mechanical and spectroscopic property profile of the aged bioplastics

Material	Aging procedure						
	Heating chamber (water)		Heating chamber (air)				Xenon-test 250, 500 and 1000h
	35°C	80°C	50°C	60°C	70°C	80°C	38°C
C, Biograde	✓	✓		✓	✓	✓	✓
CA, Cellidor	✓	✓		✓	✓	✓	✓
PTT-Sorona3301	✓	✓		✓	✓		✓
PE-LLD+PE-HD TerraleneLL1303	✓			✓	✓	✓	✓
PLA, Ingeo4032D	✓		✓	✓			✓
PLA+PE-HD RTP115375	✓			✓	✓	✓	✓
PC+PLA RTP126213	✓	✓		✓	✓	✓	✓
PA, Grilamid	✓	✓		✓	✓	✓	✓
PHA, Natureplast	✓	✓		✓	✓	✓	✓
PBS, Bionolle	✓	✓		✓	✓	✓	
TPA, Pebax	✓	✓	✓	✓	✓	✓	✓

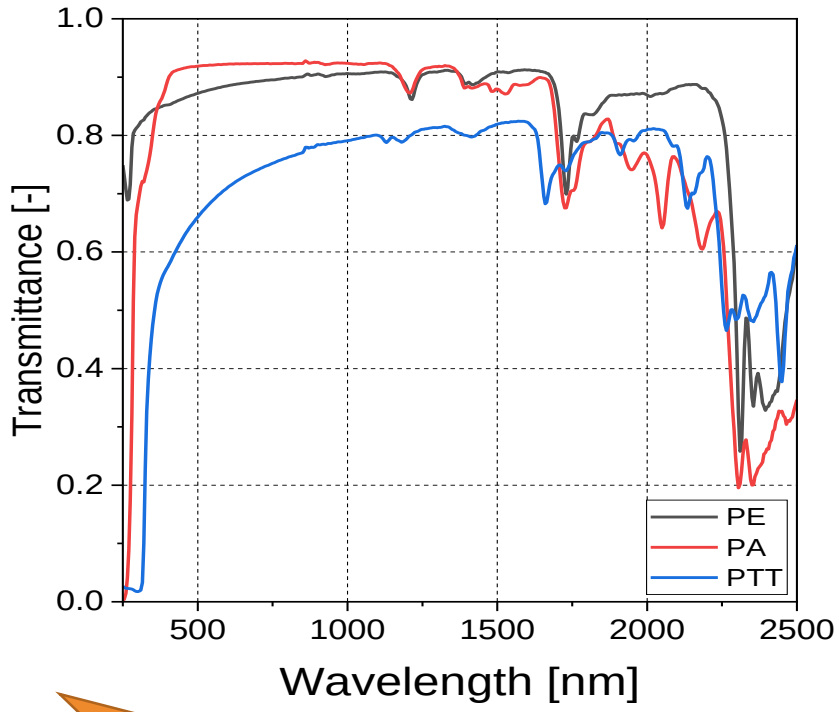
Potential materials for PV modules and properties

Potential materials for PV modules:

- **Encapsulant:** PE
- **Front cover:** PA
- **Backsheet:** PA, Polytrimethylene Terephthalate (PTT)

None of the materials fully met all the requirements

- Transparency of PE was comparatively low
- PE is by a factor of 2 to 5 stiffer than standard EVA encapsulants
- PA melting temperature close to module lamination temperatures
- PTT has glass transition within standard operating temperatures
- All materials would need stabilization in order to fulfill the long-term stability requirements



Please be aware that the project took place before the first PA backsheet cracks appeared!

Improvement of Biopolymer properties through additives

- Approx. 20 additives are used in polymeric materials
- Concentrations range from 0,05 – 70%
- Additives are used: to prevent degradation, adjust mechanical properties, …

Common used additives:

- Antioxidants
- Light stabilizer
- Heat stabilizer
- Flame retardants
- Impact modifier
- Plasticizer
- Fillers
- Colorants
- Lubricant

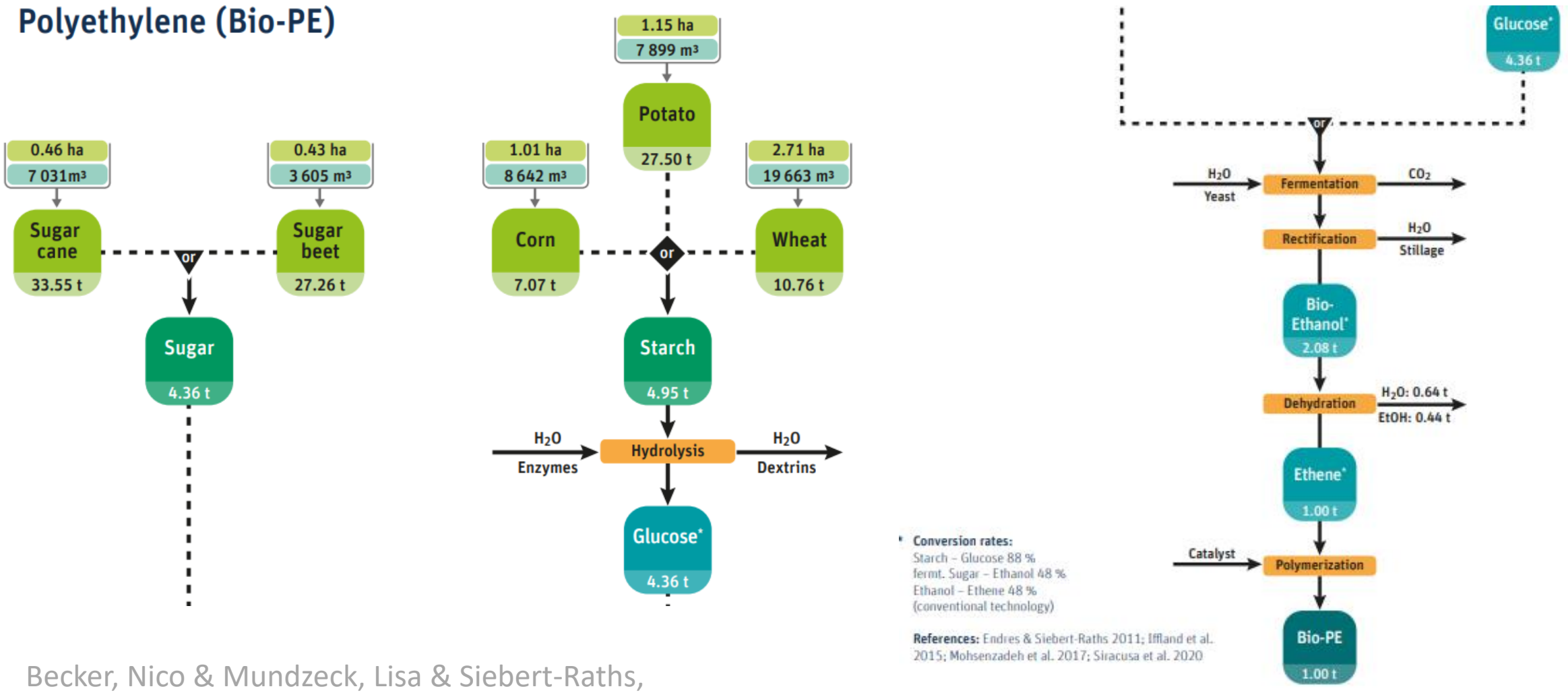
https://phoenixplastics.com/the-benefits-of-polymer-additives/

Biodegradable additives: to improve biodegradability

Cons for Biopolymer in PV application

- Most Biopolymers do not meet PV requirements → Biodegradability
- Intense production procedure and modification (additives, …) of biopolymers counteracts environmental friendliness
- Use of agricultural land for feedstock -> potential issue in terms of increasing biopolymer demand

Biopolymer production

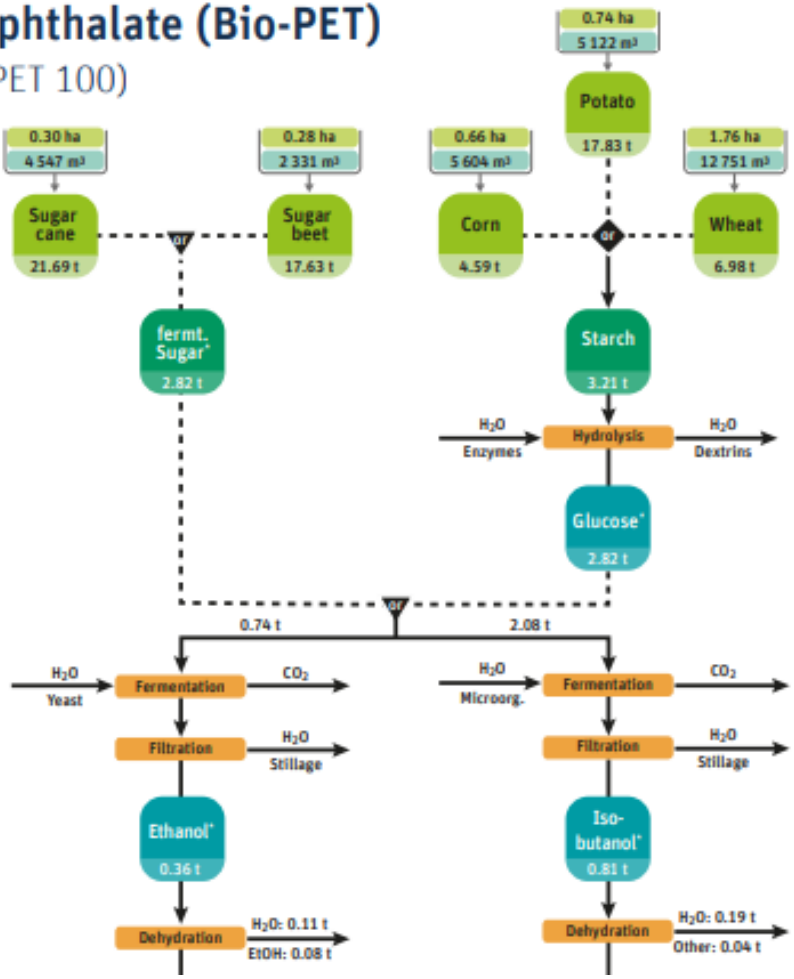


Becker, Nico & Mundzeck, Lisa & Siebert-Raths, Andrea. (2021). Biopolymers facts and statistics 2021

Biopolymer production

Polyethylene terephthalate (Bio-PET)

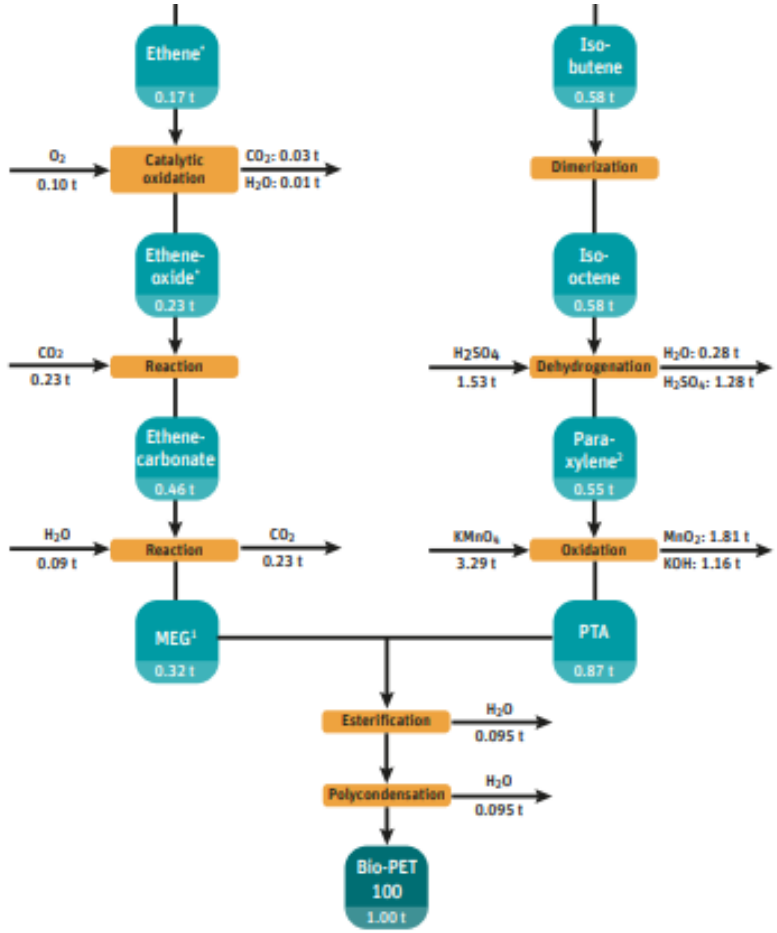
100 % bio-based (Bio-PET 100)



Omega-Process (Shell)
GEVO-Process

Conversion rates:
Starch – Glucose 88 %
Glucose – Ethanol 48 %
Glucose – Isobutanol 39 %
Ethanol – Ethene 48 %
Ethene – Etheneoxide 85 %

References: Akanuma et al. 2014; Clark et al. 2015; Collias et al. 2014; Endres & Siebert-Raths 2011; Iffland et al. 2015; Kawabe 2010; Memmo et al. 2018; Peters et al. 2011; Ryan 2019; Siracusa et al. 2020; Taffe 2008



Becker, Nico & Mundzeck, Lisa & Siebert-Raths, Andrea. (2021). Biopolymers facts and statistics 2021

PV encapsulant demand

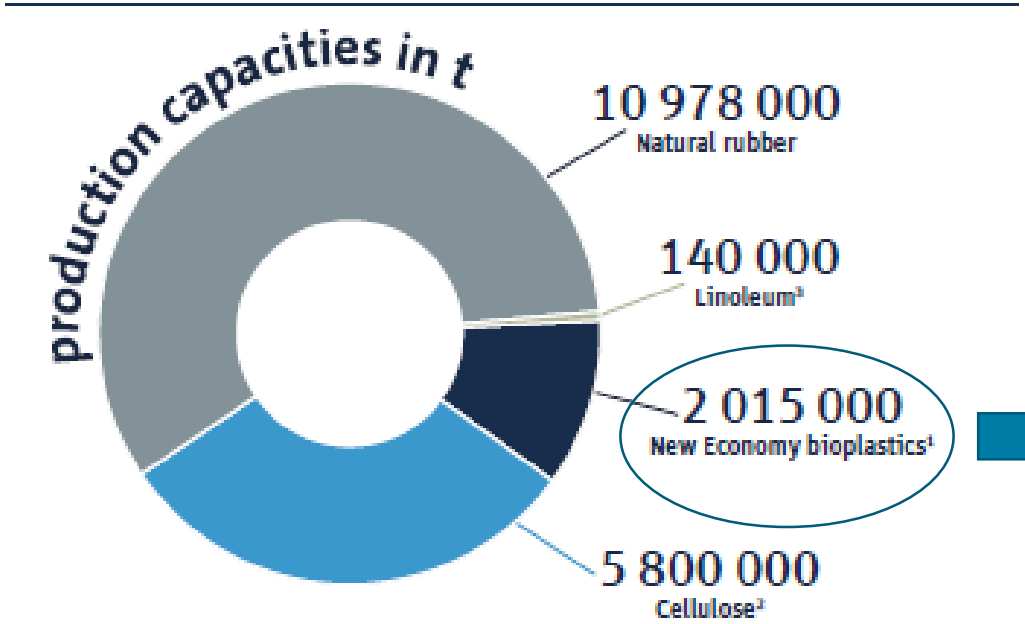
- Total demand of 917 600 tons encapsulant material in 2021 (780 000 tons EVA and 136 700 tons POE)

- Replacing of petrochemical-based EVA and POE -> **approx. 1 Mio. tons biobased encapsulant would be needed**

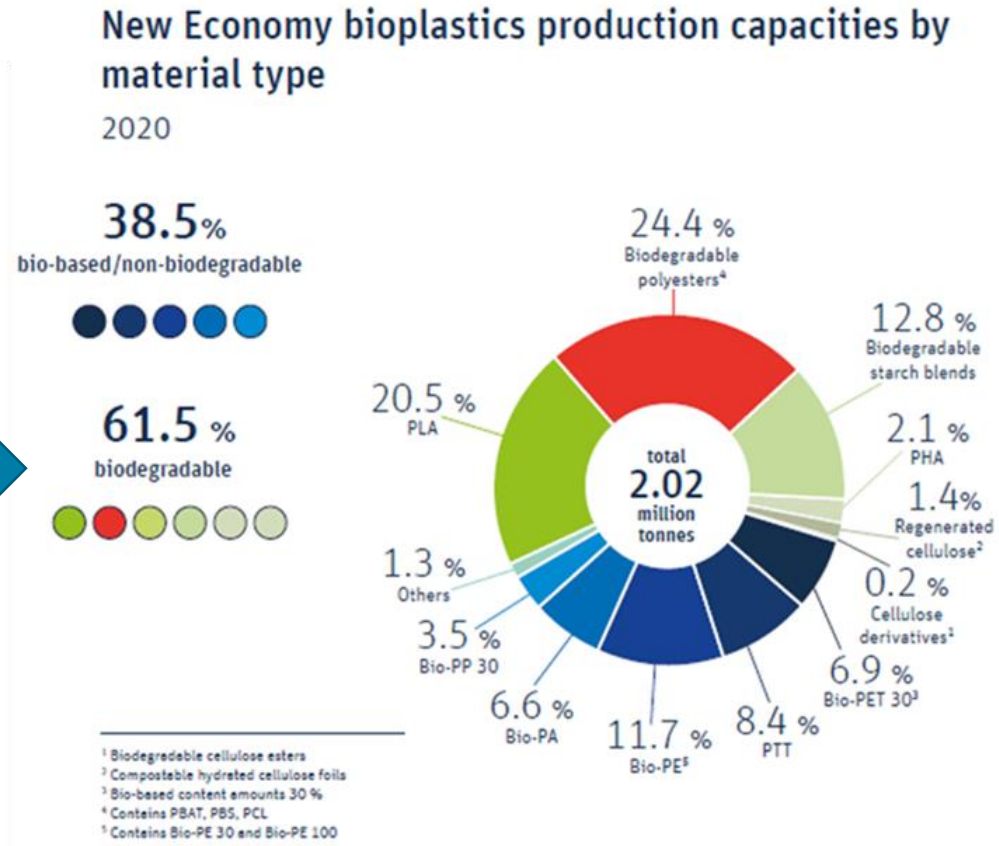
PV InfoLink	Unit	2021	2022F	2023F
Global PV demand	GW	173	212	228
Module production	GW	200	241	277
Module power output (M10 · 182)	W	540	545	550
Module surface area	m^2	2.58	2.58	2.58
Film demand/GW	Billion m^2	0.0096	0.0095	0.0094
Global film demand	Billion m^2	1.915	2.283	2.605
Share of Transparent EVA	%	52%	50%	48%
Share of white EVA	%	23%	24%	23%
Share of POE	%	10%	9%	9%
Share of EPE	%	14%	17%	20%
Weight	g/m^2	480	480	480
EVA demand	10,000 tons	78.1	93.1	105.4
POE demand	10,000 tons	13.67	16.29	19.17
Total	10,000 tons	91.76	109.3	124.53

Source: PV InfoLink, CPIA

Production capacities of Old and New economy bioplastics 2020

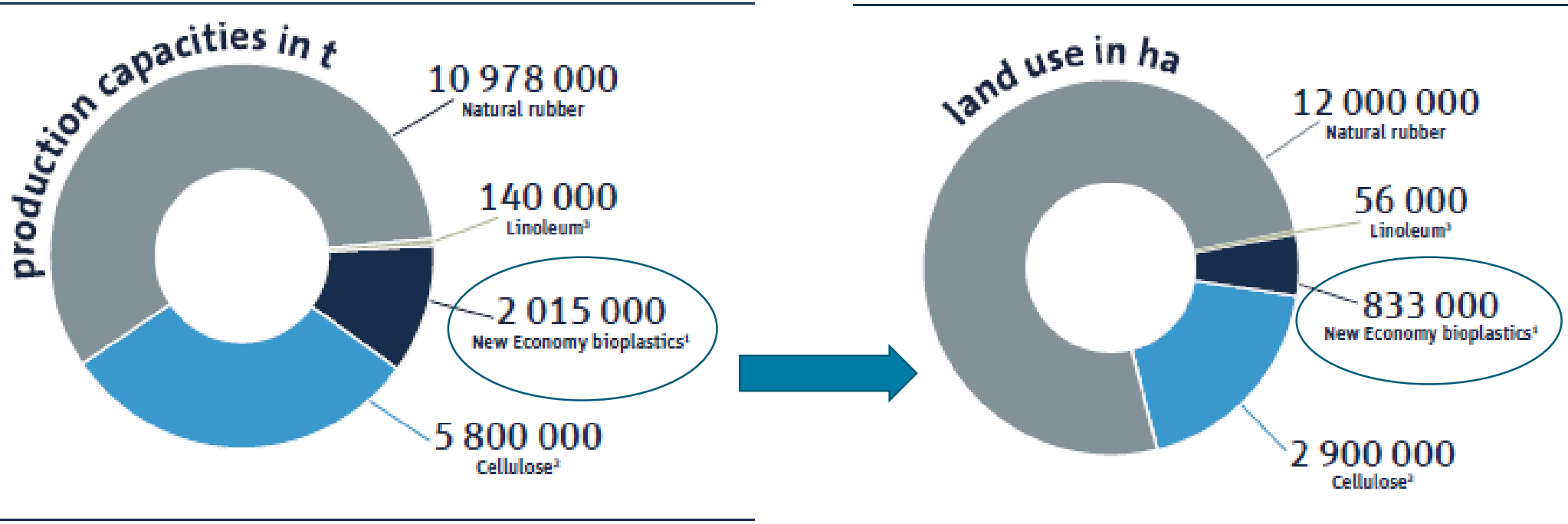


[1] PLA, PHA, PTT, PBAT, Starch blends, Drop-Ins (Bio-PE, Bio-PET, Bio-PA) and other
[2] Material use excl. paper industry
[3] Calculations include linseed oil only



➢ 2/3 of New Economy biopolymers are not suitable for PV application

Production capacities and land use of Old and New economy bioplastics 2020



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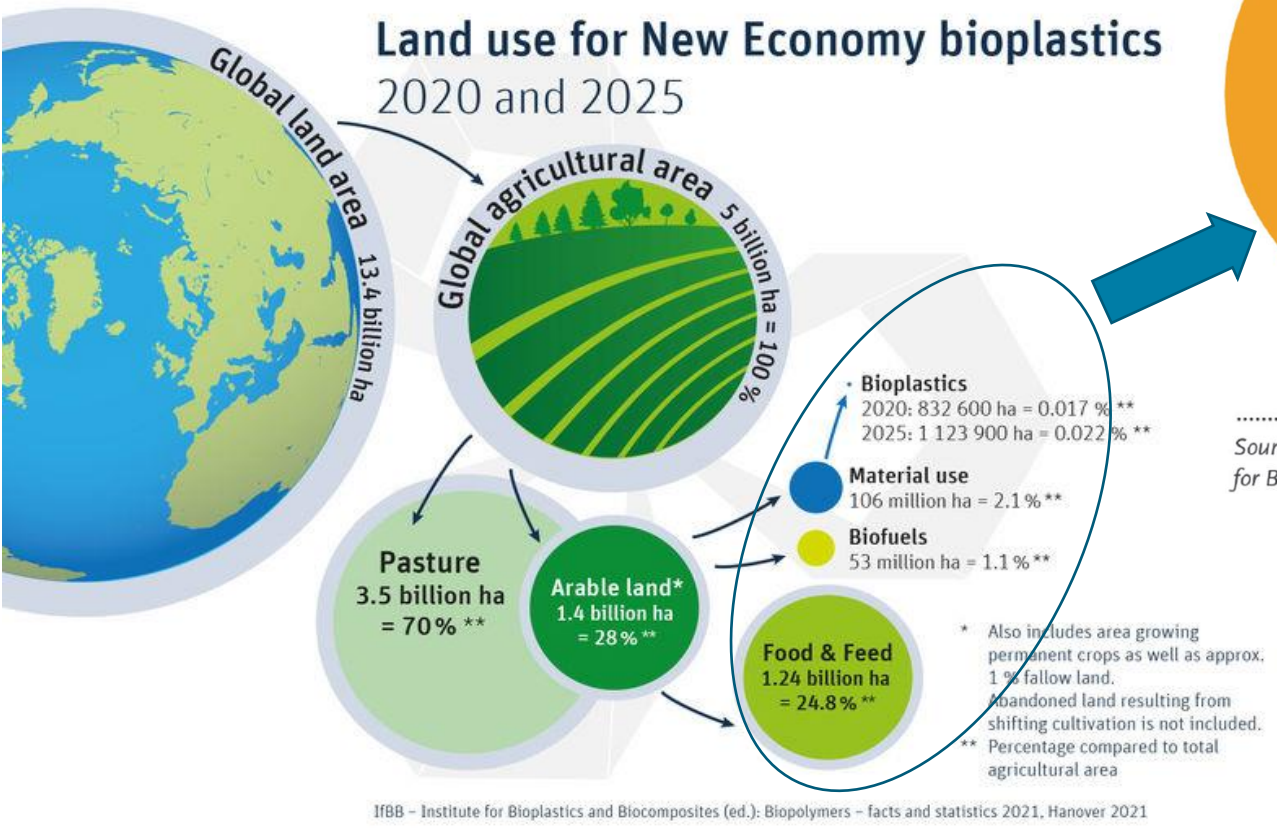
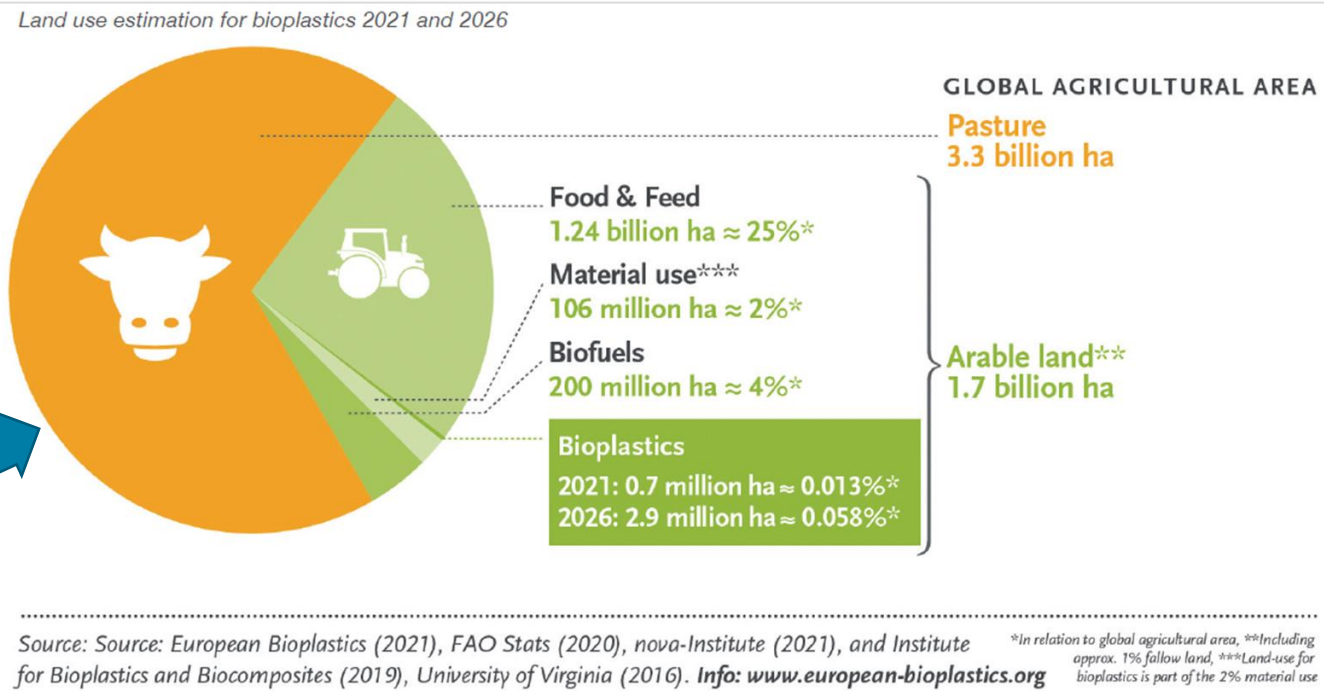
[2] Material use excl. paper industry
[3] Calculations include linseed oil only

Becker, Nico & Mundzeck, Lisa & Siebert-Raths, Andrea. (2021). Biopolymers facts and statistics 2021

Biopolymers - land use



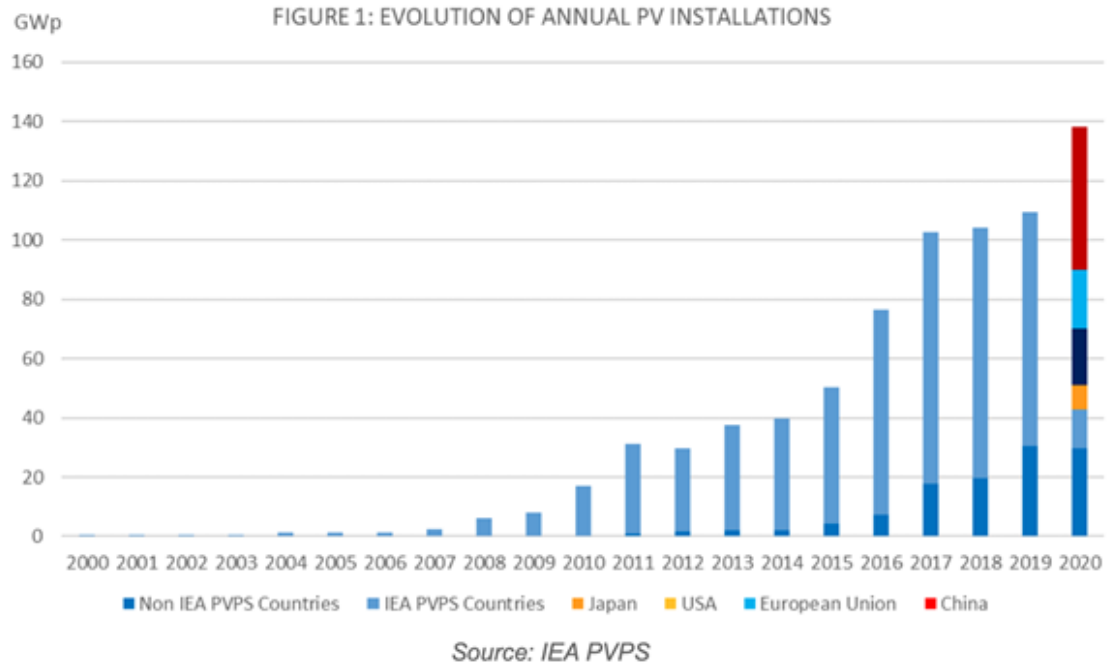
IfBB – Institute for Bioplastics and Biocomposites (ed.): Biopolymers – facts and statistics 2021, Hanover 2021

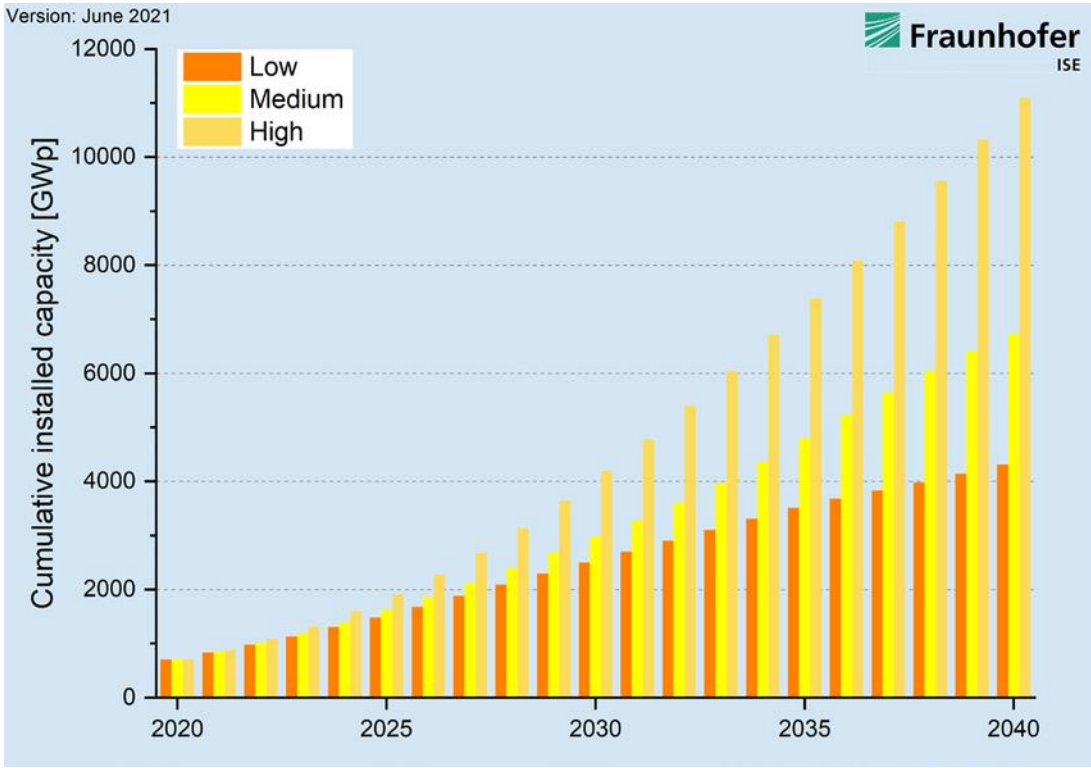


- Minor land use for biopolymers feedstock compared to agriculture in total, but additional demand leads to prioritizing -> Tortilla crises

Biopolymers – increasing demand

- Installed capacity continous to double very three years
- Capacity deployed will be immense (BloombergNEF's):
  - 2021 – 150 GW
  - 2024 – 300 GW
  - 2027 – 600 GW
  - 2030 – 1.2 TW





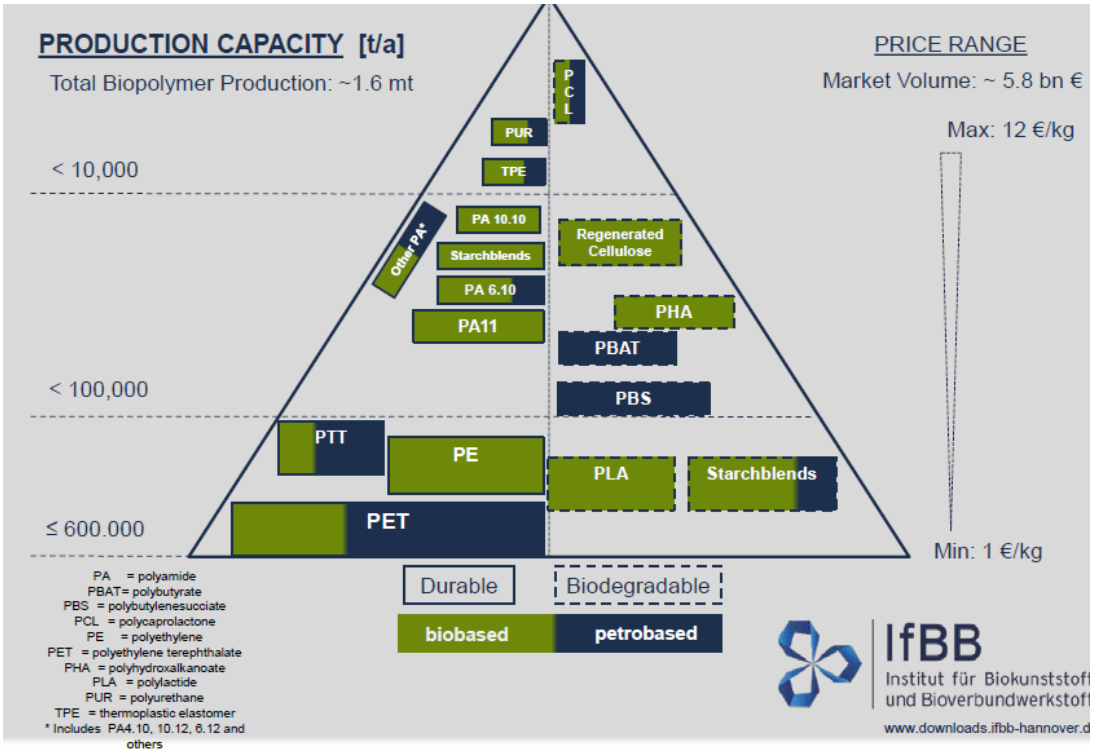
https://www.researchgate.net/publication/353549604_Levelized_Cost_of_Electricity_Renewable_Energy_Technologies_Version_2

Biopolymers - price comparison

- ***Price level of biopolymers is higher than for petrochemical-based polymers***
- ***Pricing often goes hand in hand with production volume***

Material	Source	Price (€/kg)
Lignocellulose fiber	Plant	0.4–1.2
Cellulose esters/ethers	Plant/petrochemical	4.0–20.04
Starch	Plant	0.2–2.0
Starch/polymer blends	Plant, Plant	2.0–4.0
Polylactic acid	Plant	0-2.0
Polyhydroxyalkanoates (PHA)	Plant	4.0–12.02
Polyethylene (PE)	Petrochemicals	1.31–1.6
Polypropylene (PP)	Petrochemicals	1.71–2.0
polyethylene terephthalate (PET)	Petrochemicals	1.71–1.8
PS	Petrochemicals	2.0–2.4
Polyvinylchloride (PVC)	Petrochemicals	1.71–2.02

Maraveas, C. Environmental Sustainability of Greenhouse Covering Materials. Sustainability 2019, 11, 6129. https://doi.org/10.3390/su11216129



Summary

Are biopolymers suitable for use in PV modules?

- Most available biopolymers do not meet the requirements of PV - **Biodegradability**
- Drop in biopolymers (e.g. bio-based PE, PET or PP) would meet the requirements, as they are as they are not distinguishable from conventional types

What are the challenges for replacing standard polymers with bio-based polymers

- Large discrepancy between demand and production capacity
- Strong competition with packaging industry
- Higher cost of bio-based polymers
- Increasing the production capacity means increasing the land use - competition with food production

Acknowledgements

Thank you for your attention!

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Sustainable Polymer Solutions Group, March 2022