Biopolymers for packaging

Biopolymers
CHEM-E2155

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Aalto University
School of Chemical
Engineering

Schedule

Day	Subject of lecture	Discussion part
08 January	Introduction to the course	
15 January	Biopolymers overview	Reading 1
22 January	Biopolymers for packaging	Reading 2
29 January	Discussion day	Reading 3 & Assignment 1
05 February	Biodegradation 1	Reading 4
12 February	Biodegradation 2	Reading 5
26 February	Discussion day	Reading 6 & Assignment 2
04 March	Chitin, alginates and others	Reading 7
12 March	Proteins	Reading 8
19 March	Discussion day	Reading 9 & Assignment 3
25 March	TBD	Reading 10

Learning Outcomes

After today's course you

- are familiar with the main plastic types in packaging
- know various bioplastic types
- can identify successfully implemented bioplastics in everyday products

Outline

1. **Plastics in packaging**
   - Main plastic types in packaging
   - Flows of plastic packaging materials
   - Problems

2. **Bioplastics**
   - Production capacity
   - Production routes
   - Examples

3. **Bioplastics in packaging**
   - Market drivers
   - Property map for packaging
   - Examples
   - Benefits and challenges
   - Waste management

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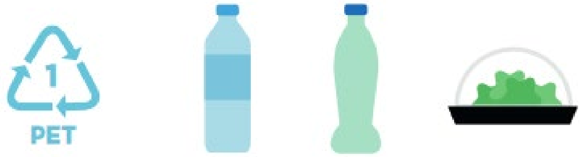
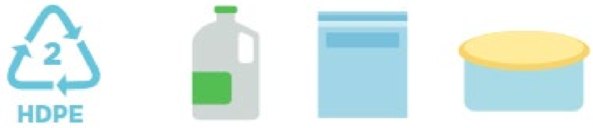
Plastic materials used in packaging?

Main plastics in packaging 1/2



Water and soft drink bottles, salad domes, biscuit trays, salad dressing and peanut butter containers



Milk bottles, freezer bags, dip tubs, ice cream containers, juice bottles, shampoo, chemical and detergent bottles

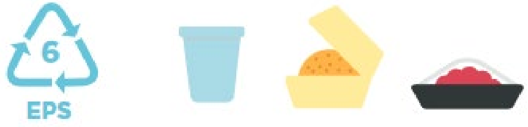
Cosmetic containers, commercial cling wrap

Squeeze bottles, cling wrap, shrink wrap, rubbish bags

Source: World economic forum, The New Plastics Economy: Rethinking the future of plastics, 2016

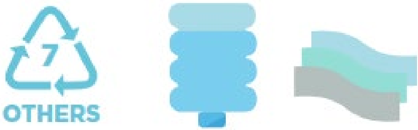
Main plastics in packaging 2/2

Microwave dishes, ice cream tubs, potato chip bags, dip tubs



Foamed polystyrene hot drink cups, burger take-away clamshells, formed meat trays, protective packaging for fragile items

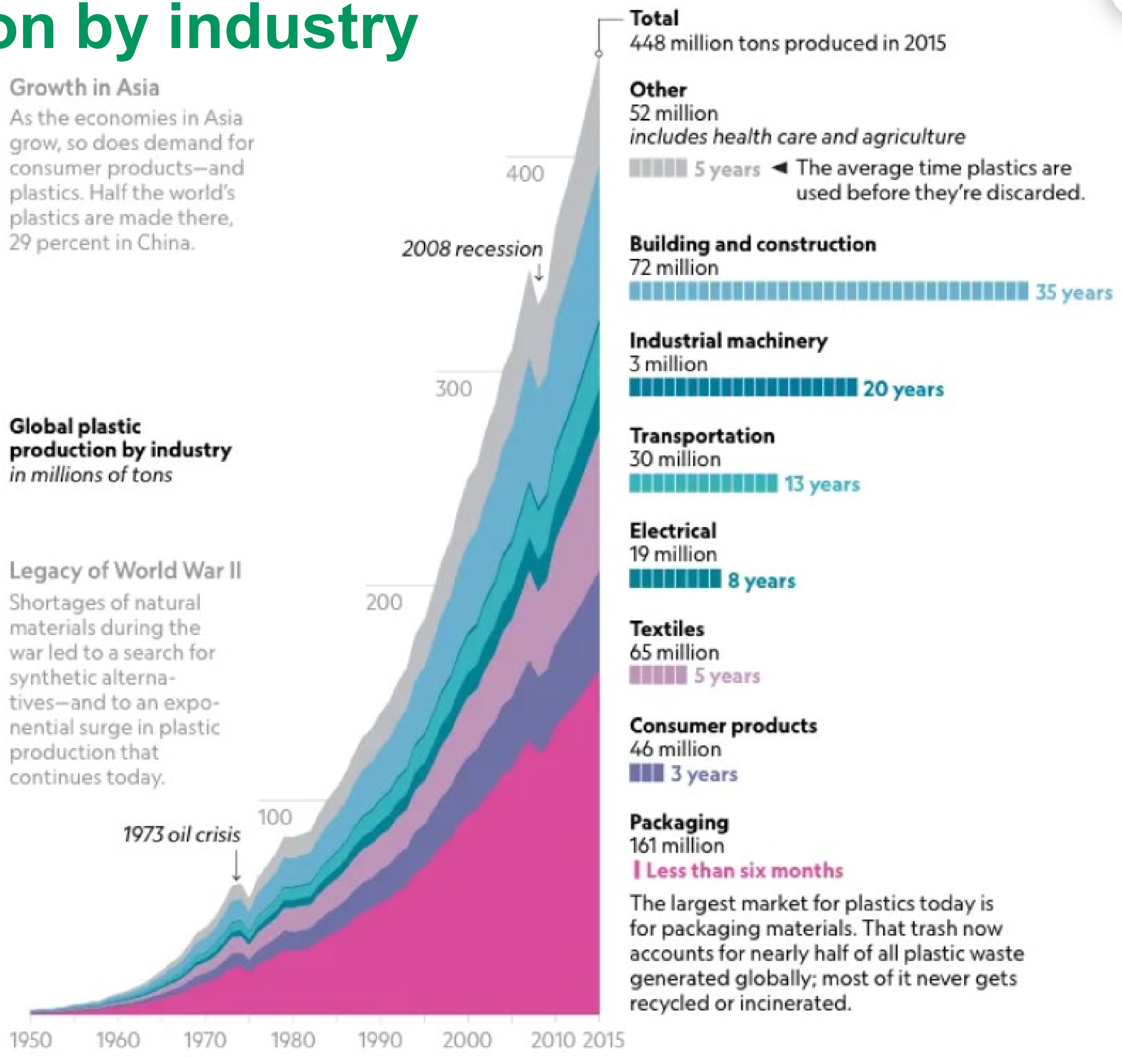
CD cases, water station cups, plastic cutlery, video cases



Water cooler bottles, flexible films, multi-material packaging

Source: World economic forum, The New Plastics Economy: Rethinking the future of plastics, 2016

Plastic production by industry



https://www.news.com.au/technology/environment/conservation/brilliant-depressing-national-geographic-cover-goes-viral/news-story/edb18ce70fbb05e5d748bb83410bc96a
Accessed 23.01.22

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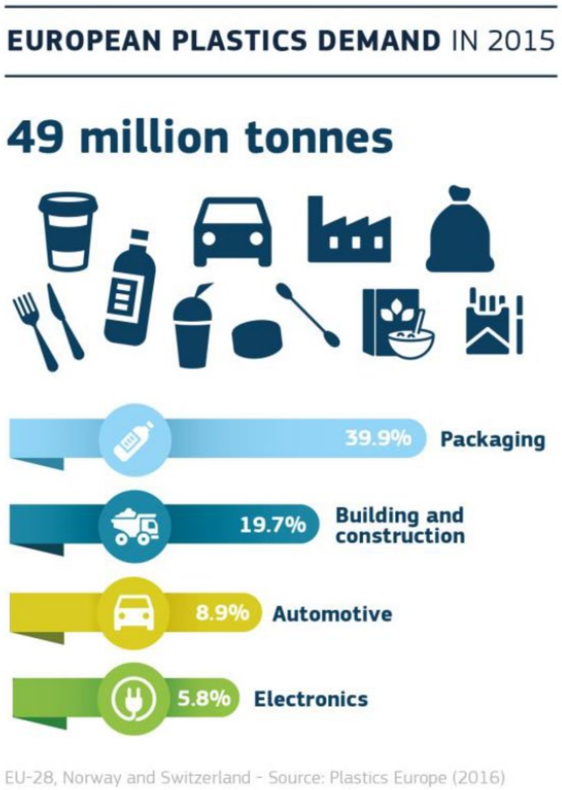
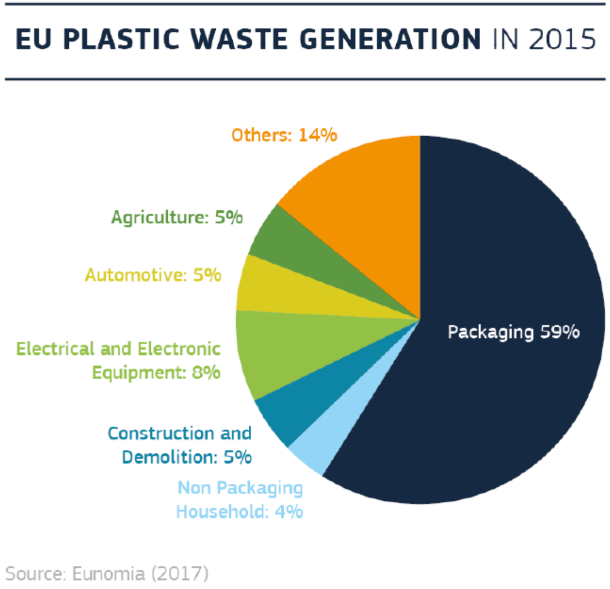
European plastic demand and waste in 2015





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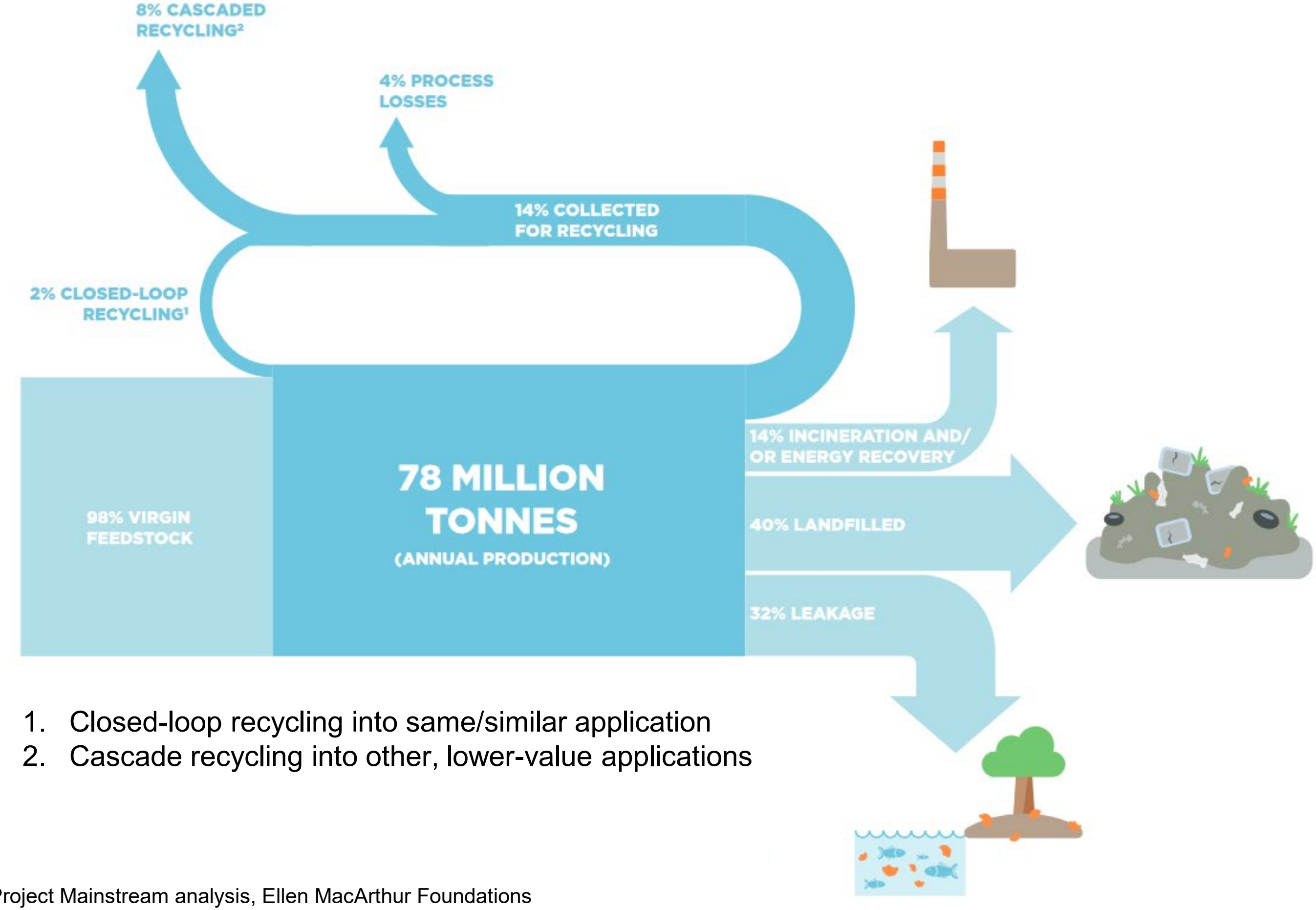
European Commission: Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions – A European Strategy for Plastics in a Circular Economy

Global flows of plastic packaging materials in 2013



1. Closed-loop recycling into same/similar application
2. Cascade recycling into other, lower-value applications

A?

Source: Project Mainstream analysis, Ellen MacArthur Foundations

Waste estimates for 2010

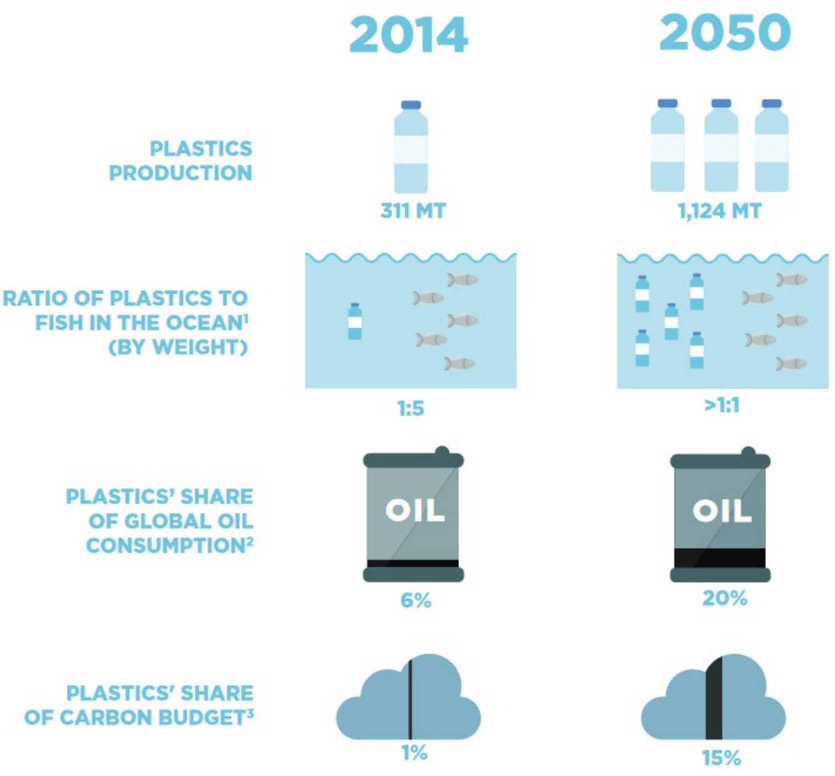
https://jambeck.engr.uga.edu/landplasticinput Accessed 23.01.22

Forecast of plastics volume growth

- 8M tonnes of plastic waste goes into oceans every year
  - more plastic than fish in the ocean by 2050

- Oil consumption expected to grow slower (0.5% p.a.) than plastics production (3.8% until 2030 then 3.5% to 2050)

- Emission of greenhouse gases by the global plastics sector will account 15% of the global annual carbon budget by 2050 (carbon budget based on 2°C increase by 2100)



Source: World economic forum, The New Plastics Economy: Rethinking the future of plastics, 2016

The problem

- Greenhouse gas emissions resulting from production and after-use incineration
- 275M tonnes total plastic waste produced annually
  - Less than 5% of plastics are recycled
- Average use of plastic bags 12 min vs. life expectancy up to 1000 years
- 150M tonnes of plastic in the oceans today
- Problems caused by plastic waste:
  - Entanglement and ingestion by animals
  - Degradation of natural systems
  - Chemical exposures
  - Cost of marine litter up to 695 M€ (to tourism and fisheries sectors)

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Sources: European Comission, Maritime forum
http://www.makeenenergy.com/home/business-areas/plastic-waste-conversion-plastcon/the-global-problem-of-plastic-waste/
https://news.uga.edu/new-science-paper-magnitude-plastic-waste-going-into-ocean-0215/

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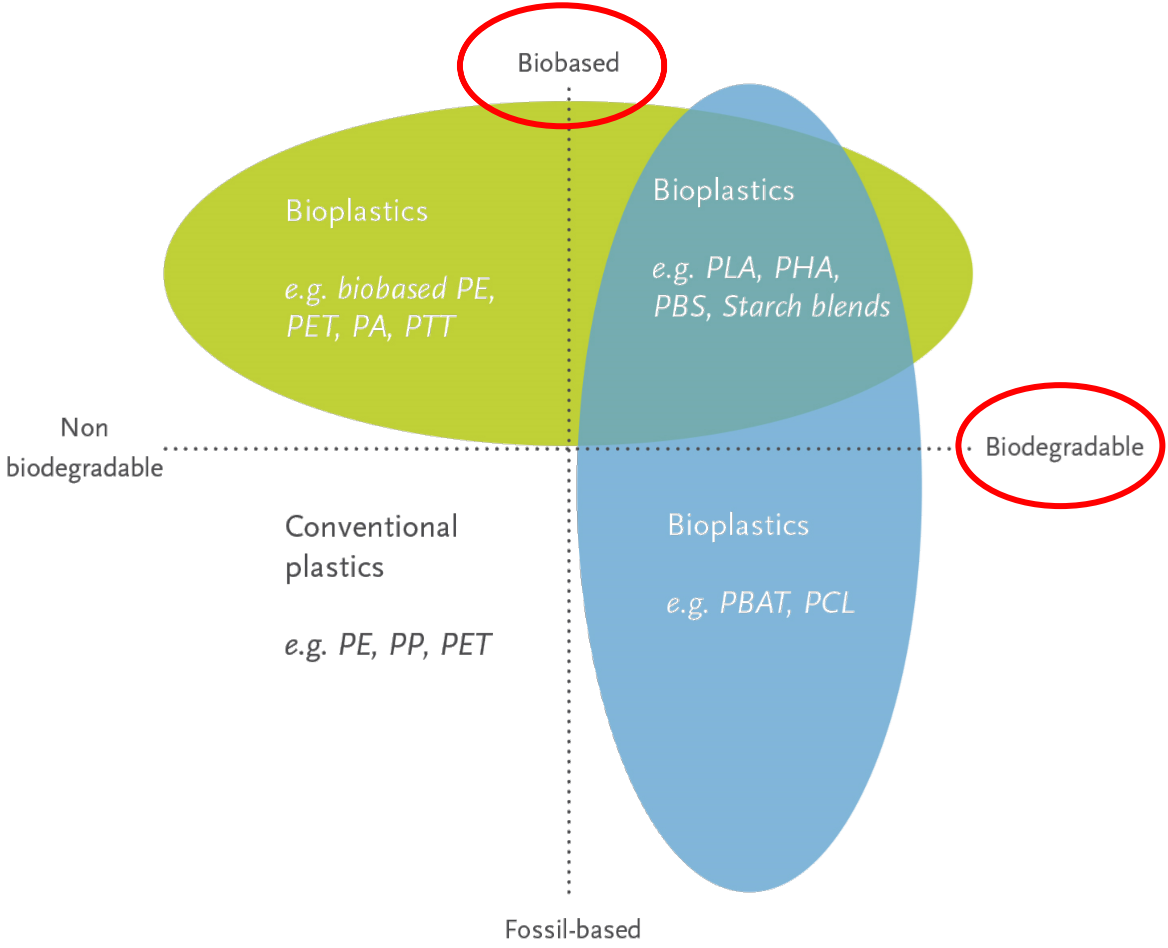
Bioplastics

- Bioplastics are biobased, biodegradable or both

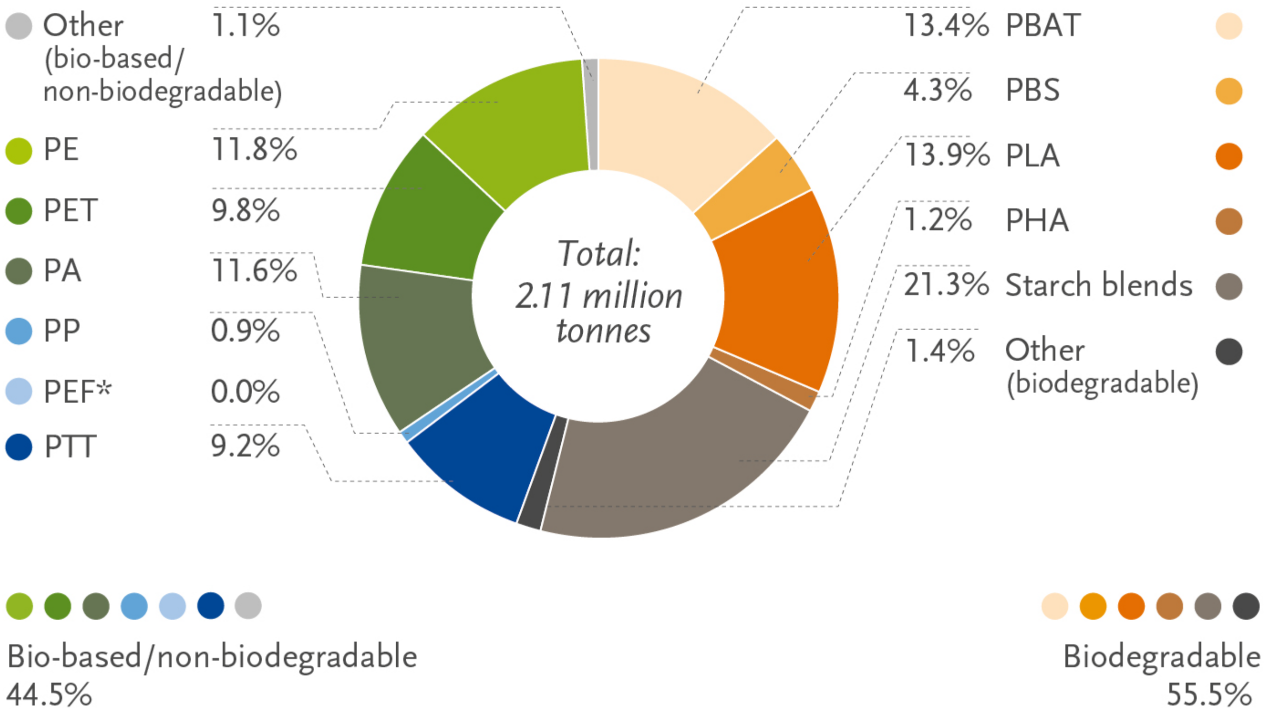
- The term biobased describes the part of a material or product that stems from biomass

- *When making a biobased claim, the unit (biobased carbon content or biobased mass content), a percentage, and the method of measurement should be clearly stated*



Source: European bioplastics

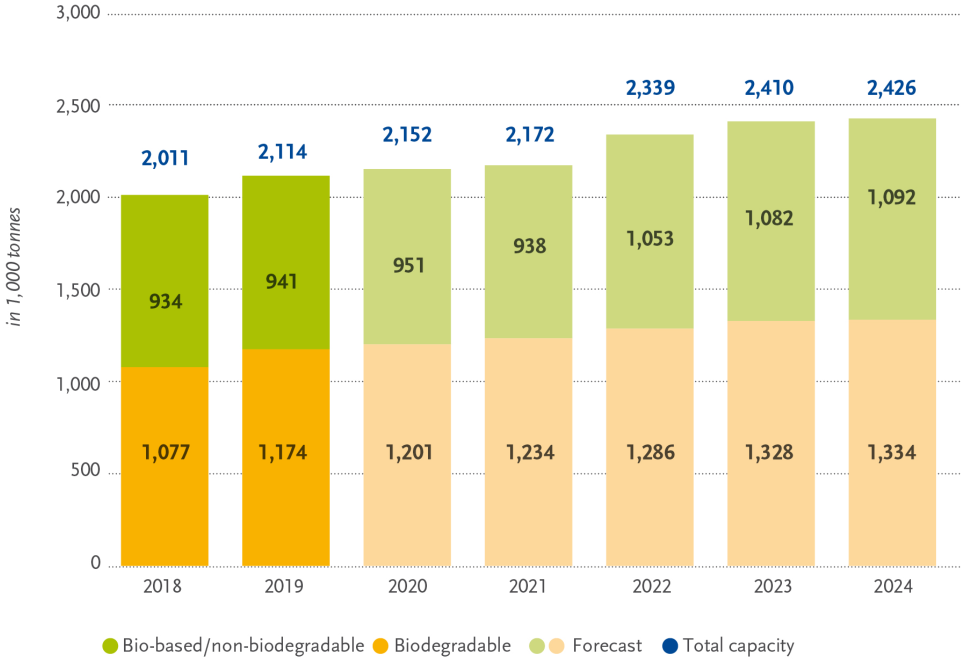
Global production capacity of bioplastics 2019



Source: European Bioplastics, nova-Institute (2019)
More information: ***www.european-bioplastics.org/market*** *and* ***www.bio-based.eu/markets***

Global production capacities of bioplastics 2018-2024

- Production of biodegradable plastics expected to increase especially due to PHA's significant growth rates
- PHAs shows highest relative growth rates with Bio-PP, which entered the market in 2019
- The production of bio-PE predicted to continue to grow
- Bio-PET production decline in previous years
  - Focus from bio-PET sifted to development of PEF (polyethylene furanoate)



Source: European Bioplastics, nova-Institute (2019)
More information: ***www.european-bioplastics.org/market*** *and* ***www.bio-based.eu/markets***

Renewable biobased feedstocks

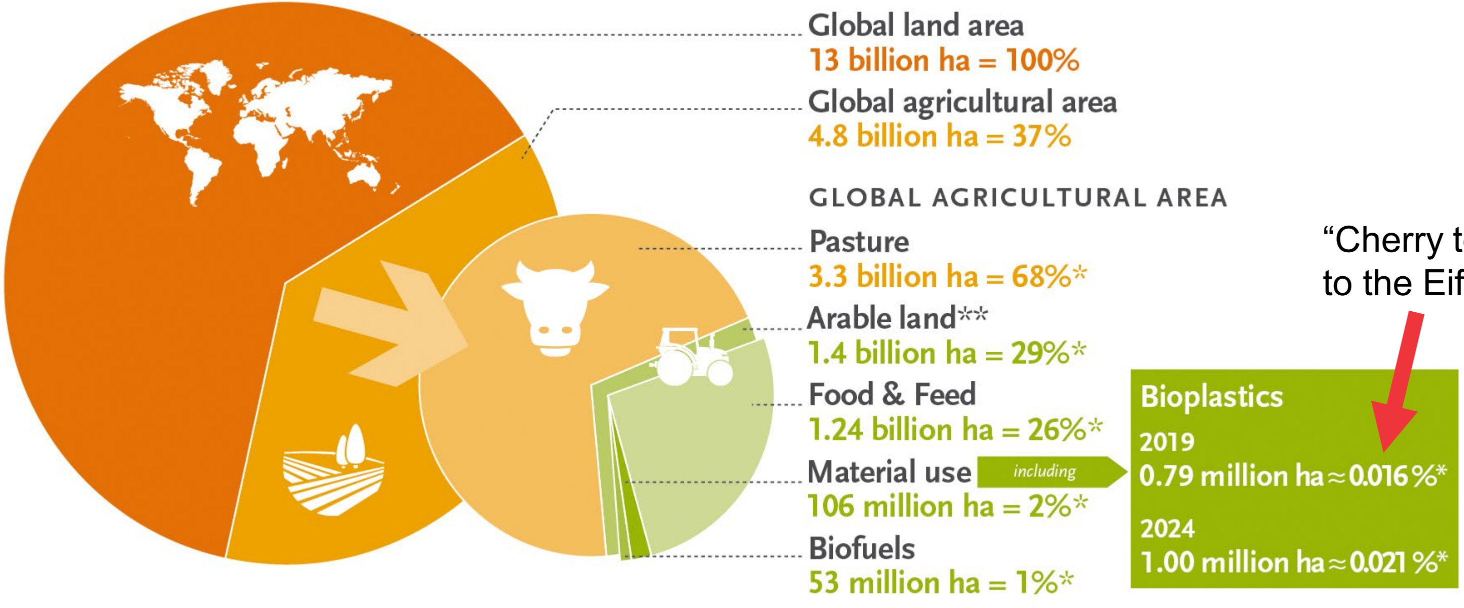
- Agro-based feedstocks (first generation feedstock)
  - Carbohydrate-rich plants such as corn or sugar cane
  - Currently the most efficient, the smallest land area needed to grow and the highest yields

- Lignocellulosics (second generation feedstock)
  - Wood and plant fibers
  - Non-edible by-products such as straw, corn stover or bagasse

- Organic waste

- **Sustainable sourcing of raw materials is important!**

Land use estimation for bioplastics 2019 and 2024



"Cherry tomato next to the Eiffel Tower"

Source: European Bioplastics (2019), FAO Stats (2017), nova-Institute (2019), and Institute for Bioplastics and Biocomposites (2019). More information: ***www.european-bioplastics.org***

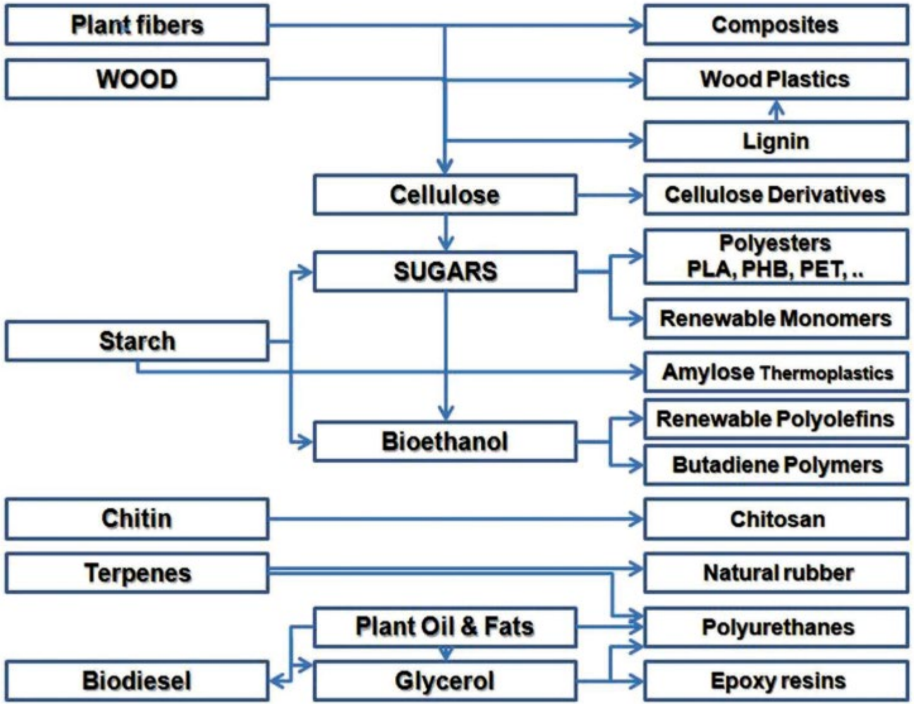
** In relation to global agricultural area*
*** Including approx. 1% fallow land*

Roadmap for biobased products

- Thermoplastic starch produced in specific dynamic-thermal conditions
  - Pressure and high shear rates disrupts crystalline starch structure

- Fermentation of glucose, obtained from lignocelluloses and starch, can be used to produce a great variety of bio-based monomers and polyolefins

- The –OH of cellulose can be reacted with various reagents to afford derivatives, such as cellulose esters (cellulose acetate, nitrocellulose)

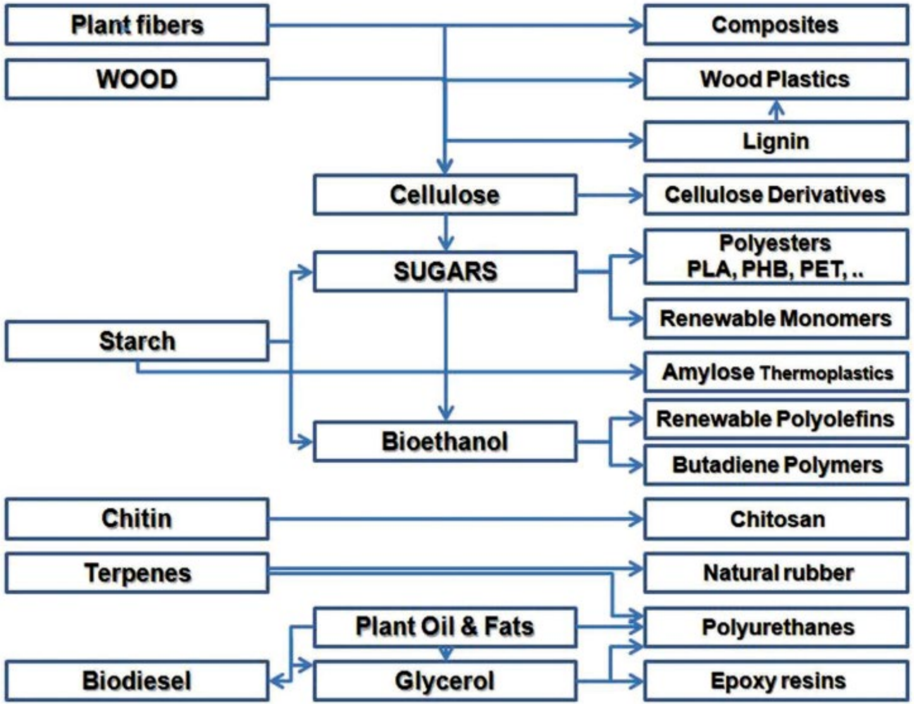


Source: Mülhaupt, R. Green Polymer Chemistry and Bio-based Plastics: Dreams and Reality Macromol. Chem. Phys. 2013, 214, 159

Roadmap for biobased products

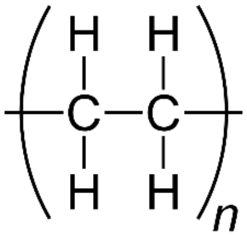
- Lignin can be depolymerized and developed into thermoplastic and thermosetting polymers
  - Arboform is moldable mixture of thermoplastic lignin with flax, hemp, and other natural fibers

- Microorganisms can produce biopolymers by bacterial fermentation of sugar or lipids
  - optimizing the conditions for the fermentation of sugar
  - extraction and purification from bacteria

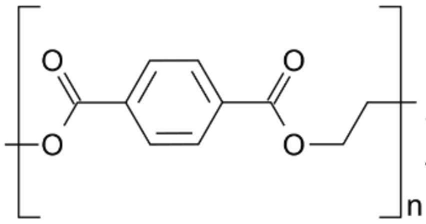


Source: Mülhaupt, R. Green Polymer Chemistry and Bio-based Plastics: Dreams and Reality Macromol. Chem. Phys. 2013, 214, 159

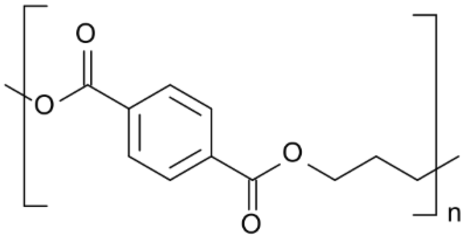
Biopolymers - biobased



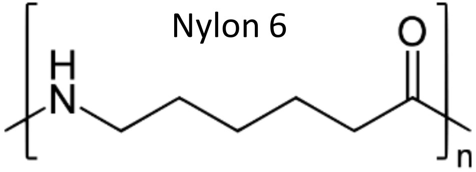
Polyethylene (PE)
made from ethanol, feedstocks including sugar cane and beet, properties identical to conventional PE



Polyethylene terephthalate (PET) is most common thermoplastic polymer resin for fibers, clothing, containers...



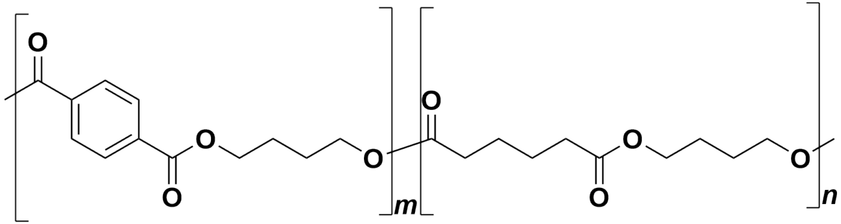
Polytrimethylene terephthalate (PTT)
similar advantages as its polyester cousins, PBT and PET



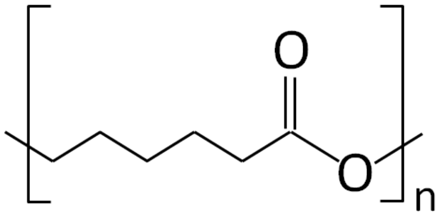
Polyamide (PA)
macromolecule with repeating units linked by amide bonds. Naturally occurring PA are proteins (wool, silk). Synthetics include nylons, sodium poly(aspartate).

Sources: Wikipedia

Biopolymers - biodegradable



Polybutylene adipate terephthalate (PBAT)
biodegradable plastic from fossil origin, used in cling wraps for food packaging and compostable plastic bags



Polycarbolactone (PCL)
biodegradable polyester from fossil origin

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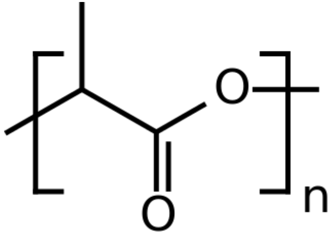
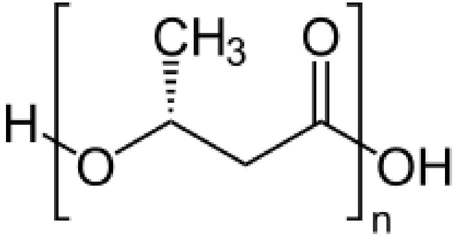
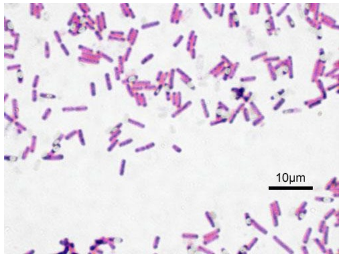
Sources: Wikipedia

Biopolymers – biobased and biodegradable

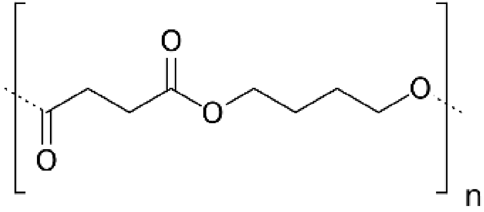


Polylactic acid or polylactide (PLA)
biodegradable thermoplastic aliphatic polyester





Polyhydroxyalkanoates (PHAs)
linear polyesters produced in nature by bacterial fermentation of sugar or lipids



Polybutylene succinate (PBS)
biodegradable aliphatic polyester with properties that are comparable to PP.
Renewable feedstocks, such as glucose, sucrose and biobased glycerol

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Sources: Wikipedia

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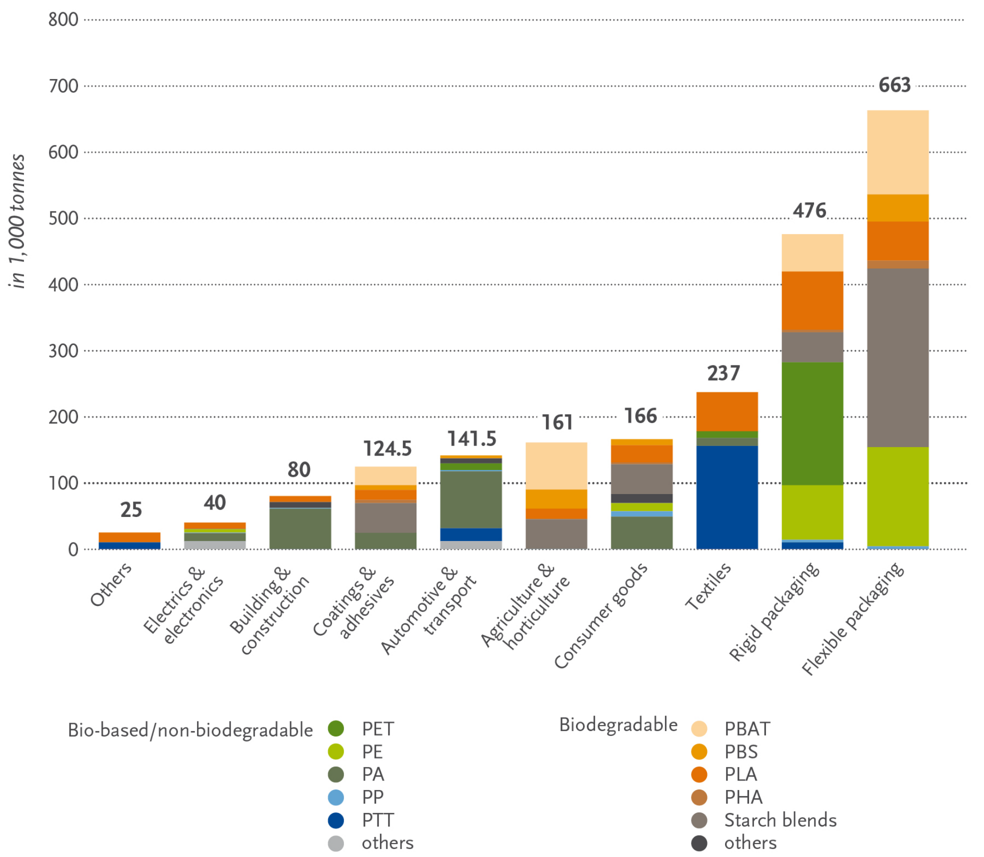
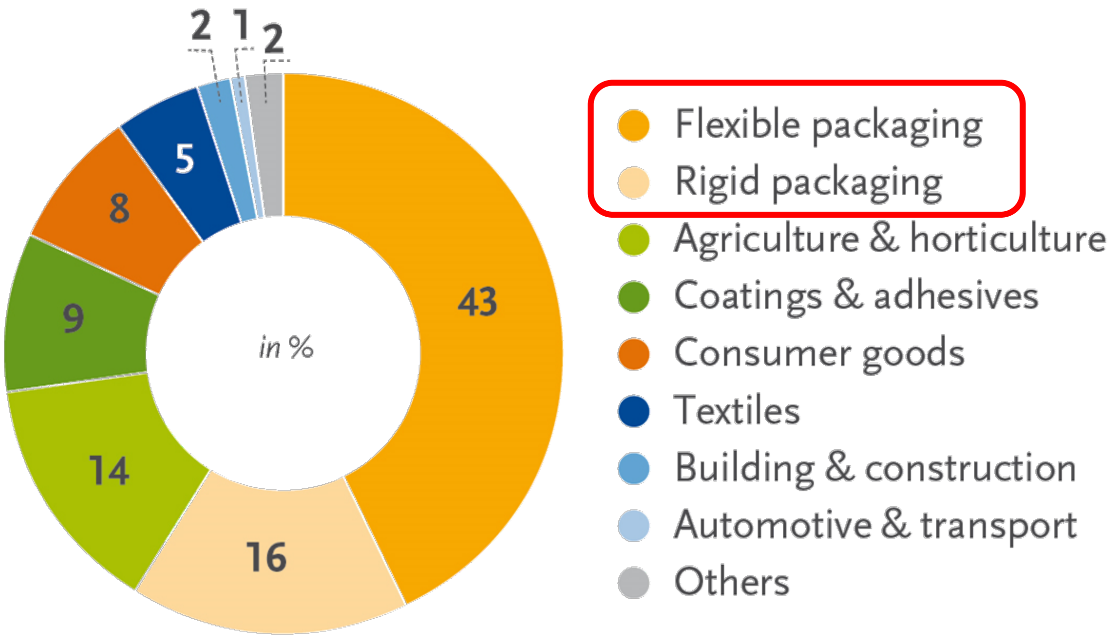
Market segments of bioplastics 2019



Source: European Bioplastics, nova-Institute (2019). More information: ***www.european-bioplastics.org/market*** *and* ***www.bio-based.eu/markets***

Biodegradable plastics by market segment 2019



Source: European Bioplastics, nova-Institute (2019). More information:
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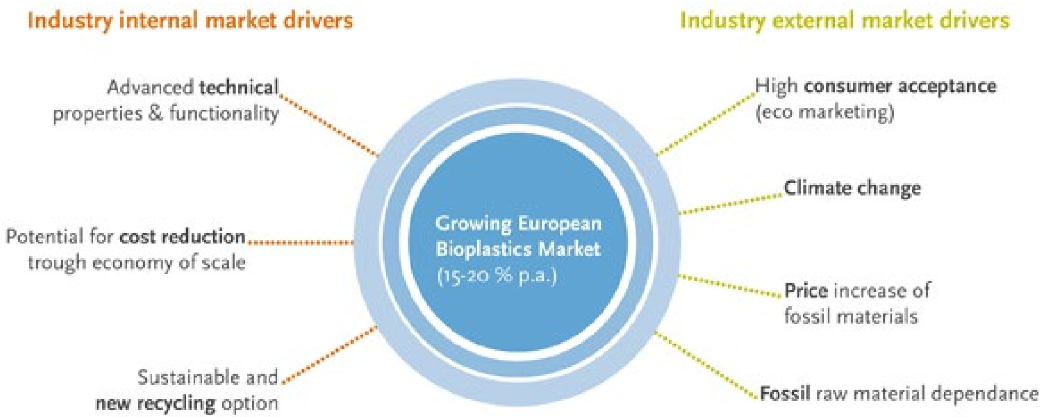
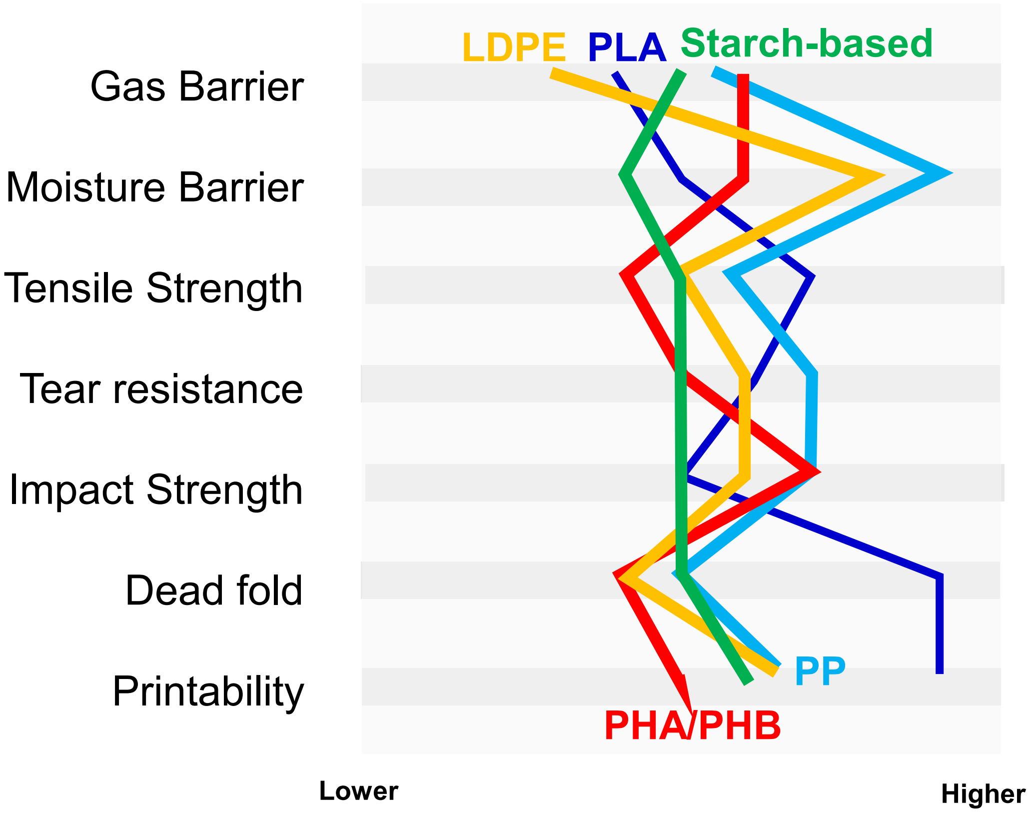
Market drivers?

Market drivers

- Consumer behavior
- Political support
- Big brands employ bioplastics for noticeable products



Biopolymer property map (packaging)



Adapted from Bioplastics and chemicals for global sustainability, 5th PTT P&R Technology day, Balaj et al, CMR, 2008

Do you now any products with bioplastic packaging?

Examples

Coca-Cola: Bio-PET PlantBottle

Bio4Pack: Compostable trays for fresh meat made from PLA

Procter & Gamble: Bio-PE shampoo packaging

Heinz partnership with Coca-Cola: Bio-PET PlantBottle

Examples

Welmu International: Woodly transparent film packaging

Huhtamäki: fiber-based ready meal pack

Spectra Biopolymers: Bottles made from 100% biobased PE and 30% biobased PET

TwistCap OSO34 (TetraPak): Tetra Rex® biobased

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Examples

PAPTIC®

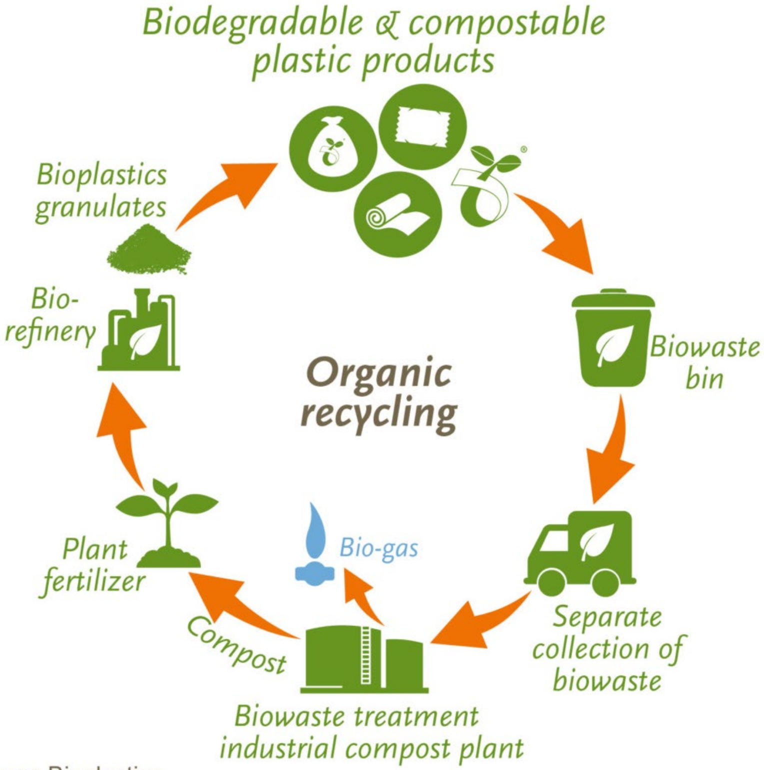
Finnish bio-packaging company

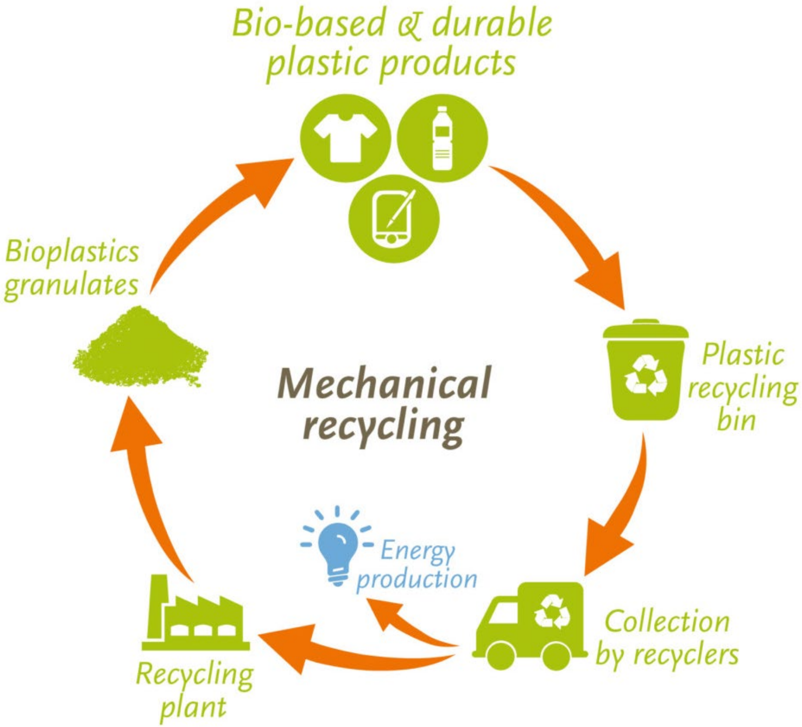
Mixture of softwood pulp fibers and a small share of thermoplastic polymer fibers (polylactides (PLA), glycolic acid polymers (PGA), polyolefins (PO), polyethyleneterephthalates (PET), polyester(PES), polyvinyl alcohols (PVA).

Using different foaming agents and binders (poly(vinyl alcohols), poly(vinyl acetates)), foam laid sheet are prepared

WO 2016/083667 A1 Fiber sheets and structures comprising fiber sheets

Waste management





Comparison of shopping bags

Table 34. Gross Energy by Activity (MJ)					
	Fuel prod'n (total)	Fuel use (total)	Transport (total)	Feedstock (total)	Total
Paper Bag (1000 bags)	493	1105	34	991	2622
Compostable Plastic Bag (1000 bags)	265	659	38	418	1380
Compostable Plastic Bag (1500 bags)	398	988	57	627	2070
Polyethylene Plastic Bag (1000 bags)	106	114	11	279	509
Polyethylene Plastic Bag (1500 bags)	159	171	16	418	763

Table 37. Global Warming Potential (CO2 Equivalents in tons)				
	Paper bag with "sequestered scenario" of carbon dioxide emissions (1000 bags)	Compostable plastic bag With 100% aerobic decomposition in landfill (1500 bags)	Compostable plastic bag with 50% aerobic & 50% anaerobic decomposition in landfill (1500 bags)	Polyethylene Plastic Bag (1500 bags)
Production	0.03	0.15	0.15	0.03
Disposal	0.05	0.03	0.22	0.00
Total	0.08	0.18	0.37	0.04

Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper.
Chet Chaffee and Bernard R. Yaros; Boustead Consulting & Associates Ltd. 2014

	Impact Summary of Various Bag Types (Carrying Capacity Equivalent to 1000 Paper Bags)		
	Paper (30% Recycled Fiber)	**Compostable Plastic**	**Polyethylene**
Total Enegy Usage (MJ)	2622	2070	763
Fossil Fuel Use (kg)	23.2	41.5	14.9
Municipal Solid Waste (kg)	33.9	19.2	7.0
Greenhouse Gas Emissions (CO2 Equiv. Tons)	0.08	0.18	0.04
Fresh Water Usage (Gal)	1004	1017	58

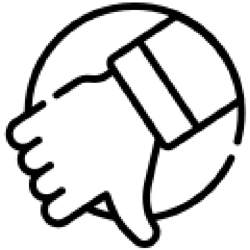
Comparison of shopping bags

Type of carrier	HDPE bag (No secondary reuse)	HDPE bag (40.3% reused as bin liners)	HDPE bag (100% reused as bin liners)	HDPE bag (Used 3 times)
Paper bag	3	4	7	9
LDPE bag	4	5	9	12
Non-woven PP bag	11	14	26	33
Cotton bag	131	173	327	393

UK Environment Agency:
Life cycle assessment of supermarket carrier bags: a review of the bags available in 2006
Report: SC030148

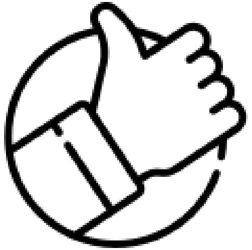
Challenges of bioplastics in packaging

- Biodegradation in landfills can produce methane gas
- Biodegradable bioplastics don't always readily decompose, conditions need to be right
- Bioplastics are made from plants, so land that could be used to grow food is being used to “grow” plastic instead
  - Water pollution caused by runoff fertilizers
  - Energy crop monocultures threaten biodiversity
- Bioplastics and biodegradable plastics cannot be easily recycled?
  - PLA looks very similar to PET but, if the two are mixed up in a recycling bin, the whole collection becomes impossible to recycle



Benefits of bioplastic in packaging

- Save fossil resources by using biomass or waste materials
- Domestic raw material supplies offer more possibilities, less dependence on oil imports
- Biodegradability offers additional means of recovery at the end of a product’s life
  - Recyclable, compostable and biodegradable packaging
- People show interest in green living, bio-packaging presents an opportunity for growth
  - Consumers likely to purchase from business with an identity eco-friendly practices



Summary questions

- Name types of polymers currently used in packaging
- What are the main bioplastics currently produced?
- What are the strengths and weaknesses of bioplastics in respect to packaging?

Reading discussion peer grading

You will submit your peer-grading file at the end of the course

Legend:

present:	no = 0; yes = 1	
camera on:	no = 0; yes = 1	
active participation in discussion:		little to none = 0; ok = 1; very good = 2
active participation in preparing Padlet content:		little to none = 0; ok = 1; very good = 2

points	grade
50-45	5
40-44	4
35-39	3
30-34	2
25-29	1
0-24	0

Group 1	Discussion of Reading 1				
	present	camera on	active participation in discussion	active participation in preparing Padlet content	score
Name1					0
Name2					0
Name3					0
Name4					0
Name5					0

Reading 2 discussion

Chapter title: Biopolymer-Based Sustainable Food Packaging Materials: Challenges, Solutions, and Applications
By Perera *et al.*
From: *Foods* 2023, 12, 2422

Discussion items:

- **What are important material properties for packaging?**
- **Which ones are difficult to achieve with biopolymers and why?**
- **Pick an oil-based packaging and propose (a combination of) biopolymers that could potentially substitute it.**

Instructions:
Write your summary in e.g. PowerPoint. Save the text as image file (.jpg) and upload it to the Padlet page:
https://padlet.com/michaelhummel/CHEME2155_2024