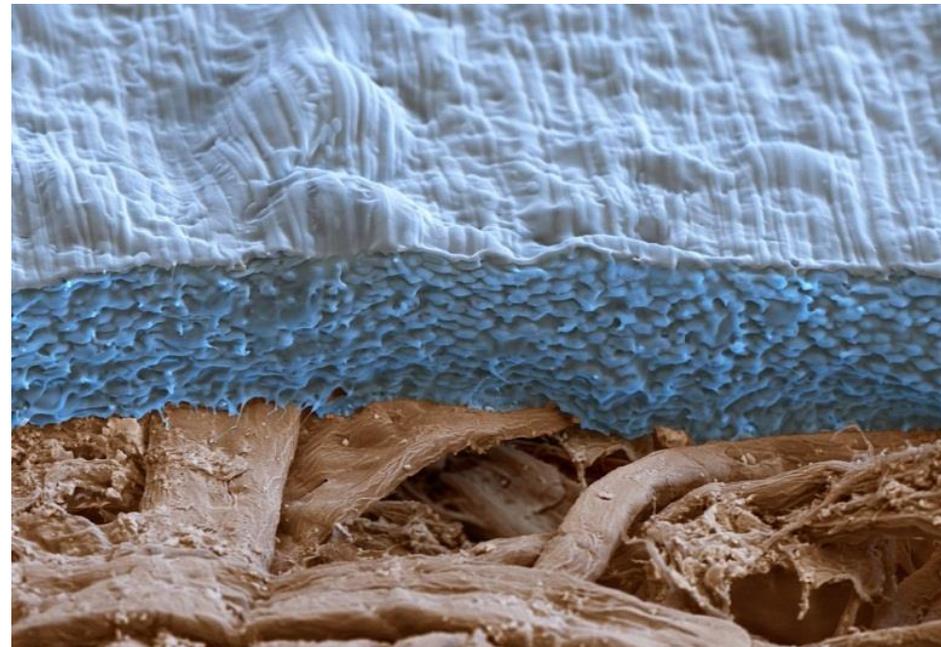
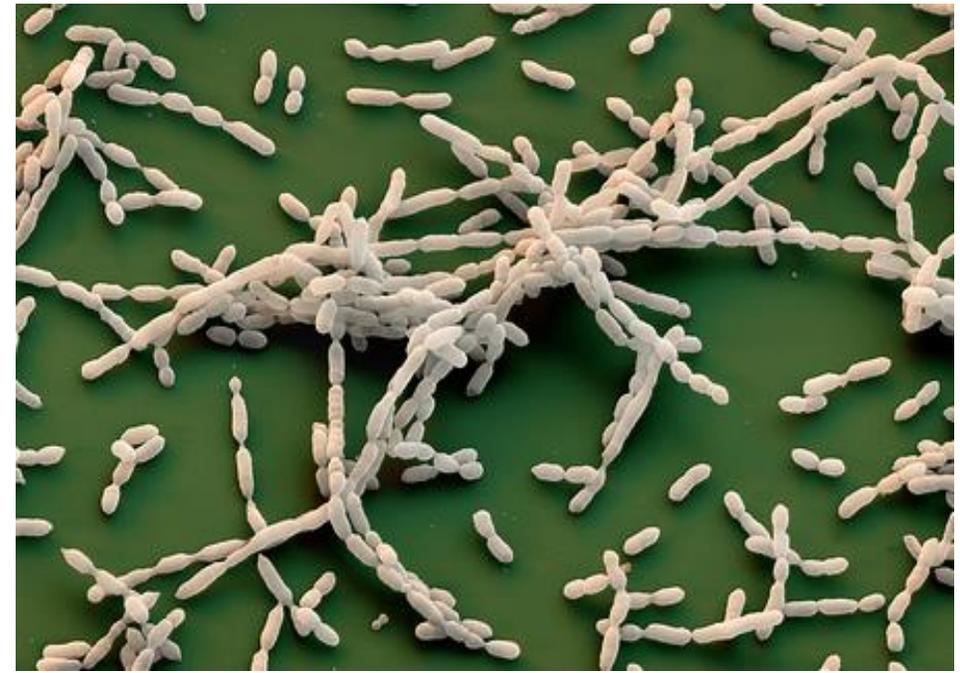


# The small compendium of biodegradable and biobased materials

## Part 2: Biodegradable and biobased polymers and applications

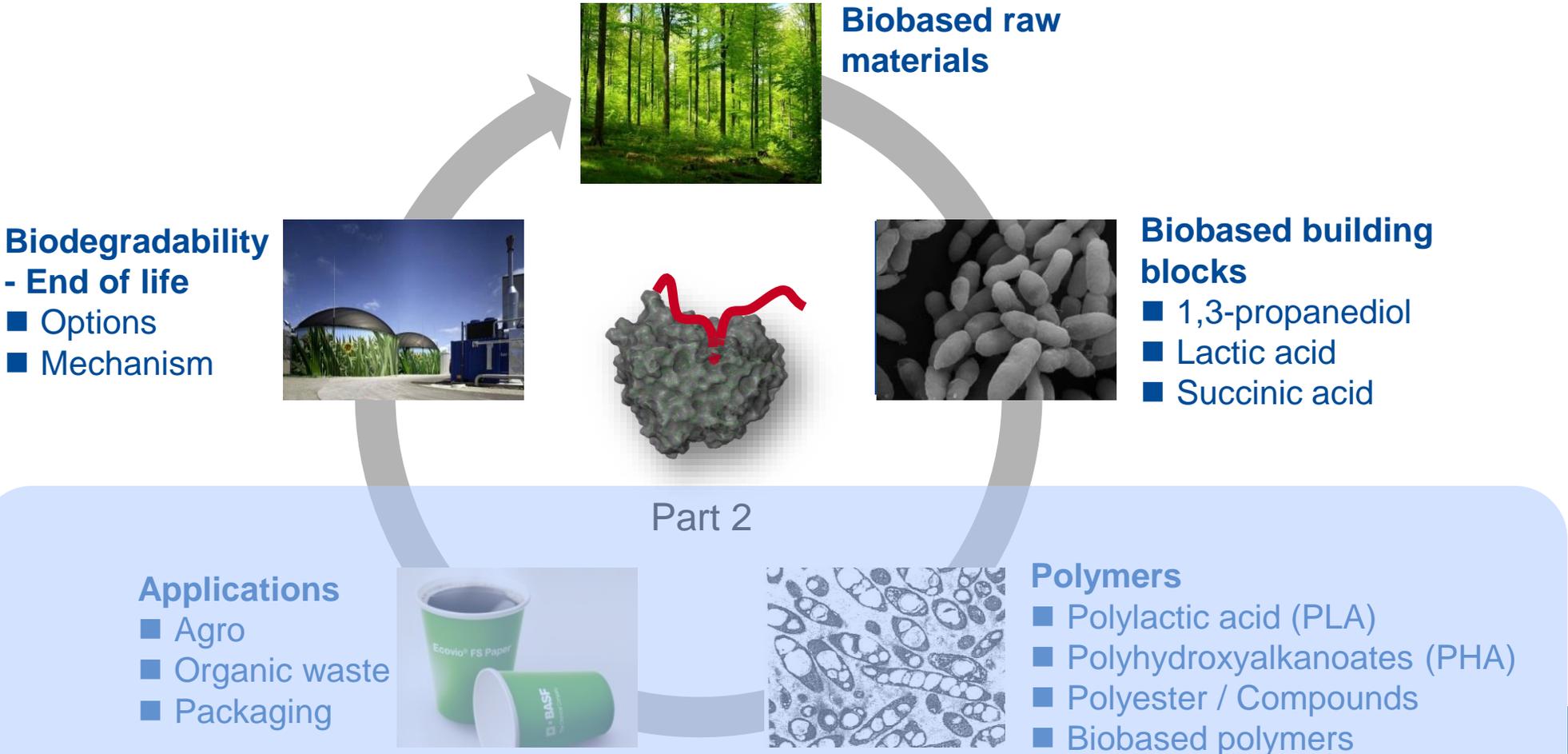
Andreas Künkel, Vice President  
Biopolymers Research BASF SE  
Version 2021



Symbiosis of  
Chemistry  
and Biology

Overview

# Content overview of the small compendium of biodegradable and biobased materials



## Summary part 2: Biodegradable and biobased polymers and applications

### **Biodegradable and biobased polymers**

- Polylactic acid has been established in world scale production with extended property profile
- Polyhydroxyalkanoates are becoming available in production scale with a very broad biodegradation profile
- PBAT production capacity is increased significantly on global level incl. versions and variants with biobased content
- World scale PBS production established

### **Market and applications**

- Legislative measures support the development for biodegradable and biobased materials
- Public perception is very different with respect to sustainability benefits
- Organic waste management is enforced – biodegradable bags as enabler
- Biodegradable mulch films prevents negative impacts on soil
- Different biodegradable packaging solutions are available with a broader application scope from paper coating, biodegradable coffee capsules to foams
  
- Durable and biobased polymers are available for different applications

# Biodegradation

## The circular economy vision with use of biodegradable and biobased materials – how to close the nutrient loops



➔ Biodegradable polymers as enabler for organic waste recycling and closing the loop – case study e.g. Milan (Italy)



## Introduction to part 2

# Applications for biodegradable plastic materials



Biodegradable plastics offer reduced system costs for a series of single and/or short-term use applications: for organic waste collection, in agricultural and horticultural sectors (e.g. as mulch-films) and in food packaging

## Overview part 2

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### ■ Biodegradable and biobased polymers

- Polylactic acid (PLA)
- Polyhydroxyalkanoates (PHA)
- Polyester / Compounds

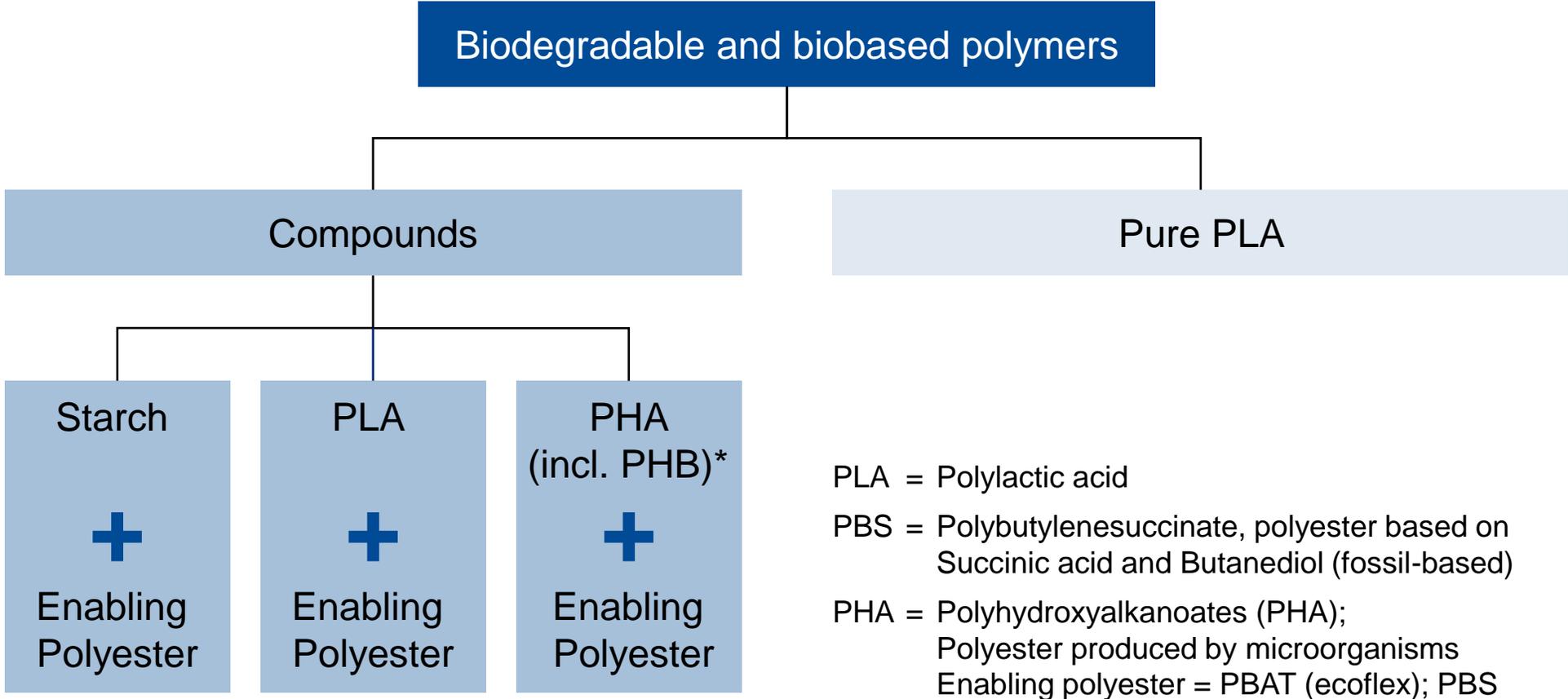
### ■ Applications of biodegradable and biobased polymers

- Market, legislation, capacities & application overview and public perception
- Agricultural mulch film
- Organic waste management
- Packaging

### ■ Durable and biobased polymers

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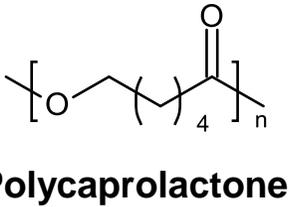
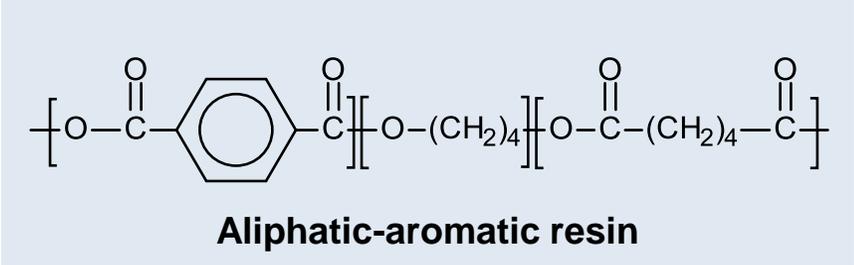
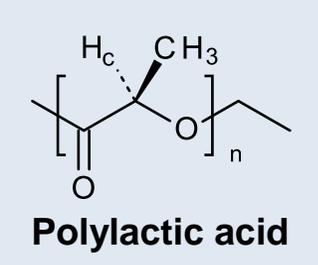
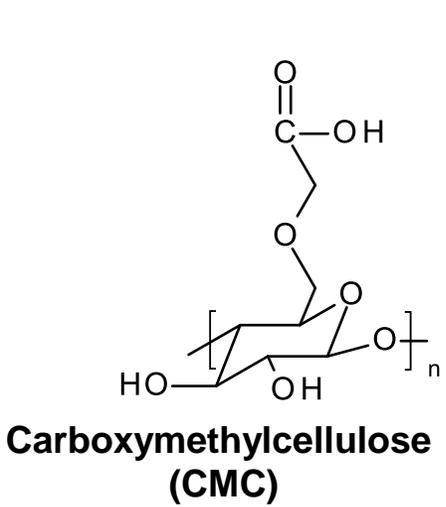
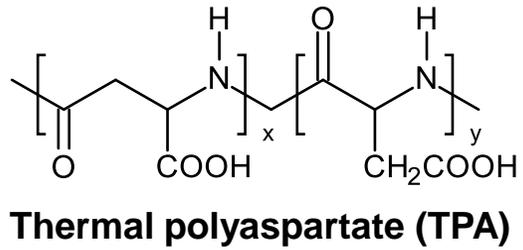
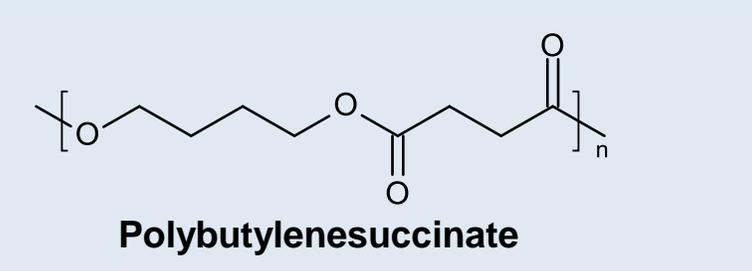
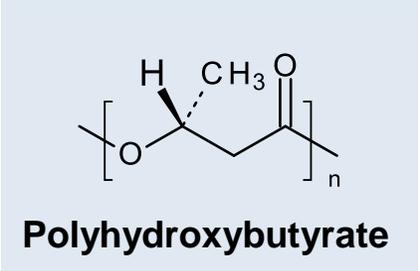
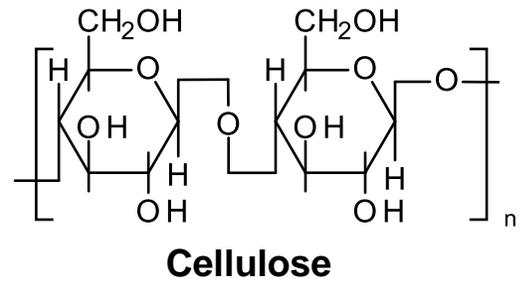
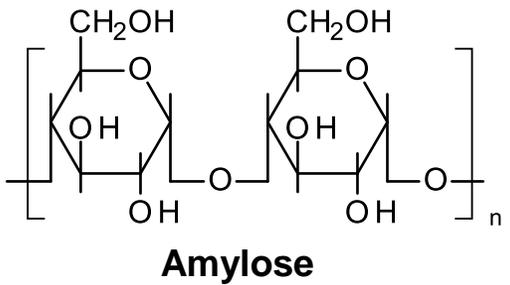
# Biodegradable and biobased polymers and compounds



\* Intention of PHA/PHB producers: launch pure PHA products

# Polymers

## Structures of selected biodegradable polymers



Blue boxes = described in next chapters

# Polymers

## Biodegradable polymer composition and technology type

Polymer	Raw material	Monomer	Polymer	Comment
PLA	Corn			Ratio of D- and L-lactic acid influences properties
PHA	Corn			Different “monomers” influence properties
Polyester (ecoflex, PBS)	Different fossil or biobased monomers			Different monomers (aliphatic and aromatic) and ratio influence properties

= biotechnological step  
 = chemical synthesis

## Overview part 2

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### ■ Biodegradable and biobased polymers

- Polylactic acid (PLA)
- Polyhydroxyalkanoates (PHA)
- Polyester / Compounds

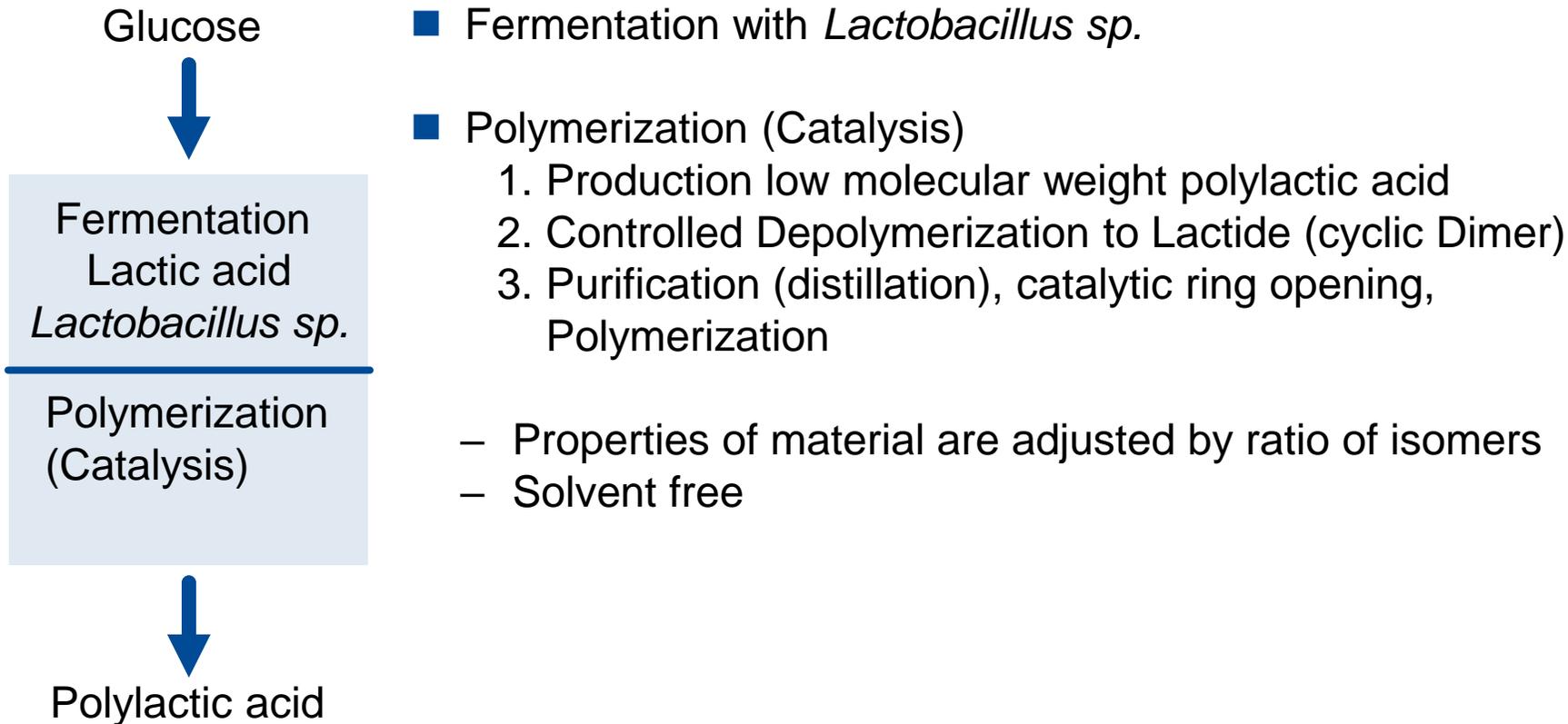
### ■ Applications of biodegradable and biobased polymers

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- Packaging

### ■ Durable and biobased polymers

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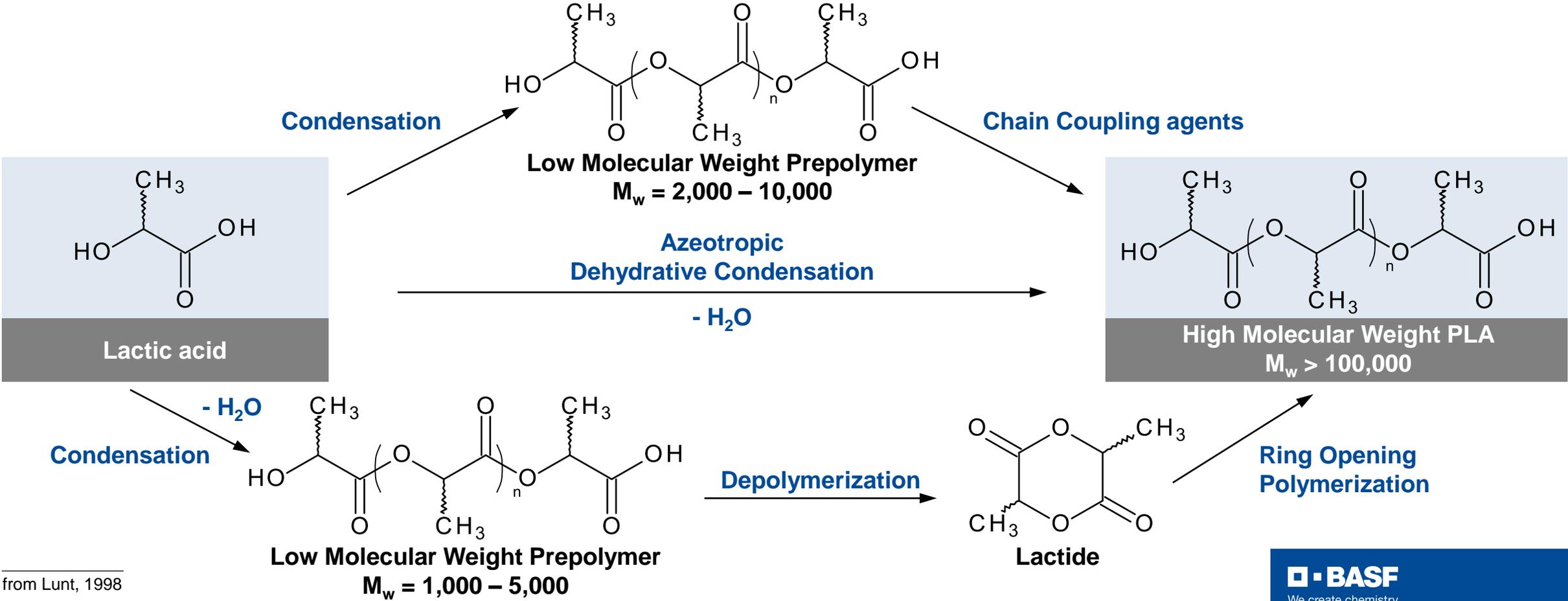
## Biodegradable polymers – NatureWorks<sup>#</sup> process for PLA



# = Development started by Cargill, until 2005 in Joint Venture with Dow

# Poly(lactic acid)

## Biodegradable Polymers – Poly(lactid) acid synthesis options



Polylactic acid

# Biodegradable Polymers – Production process of Cargill / now NatureWorks

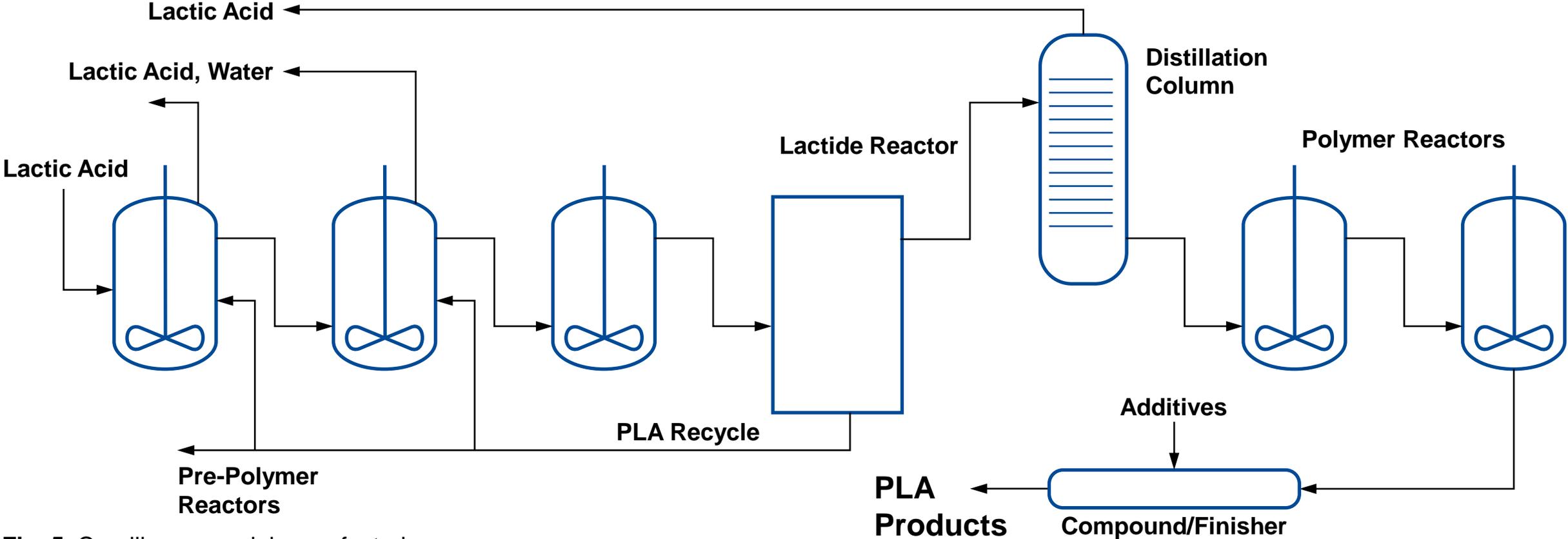


Fig. 5. Cargill commercial manufacturing process

from Lunt, 1998

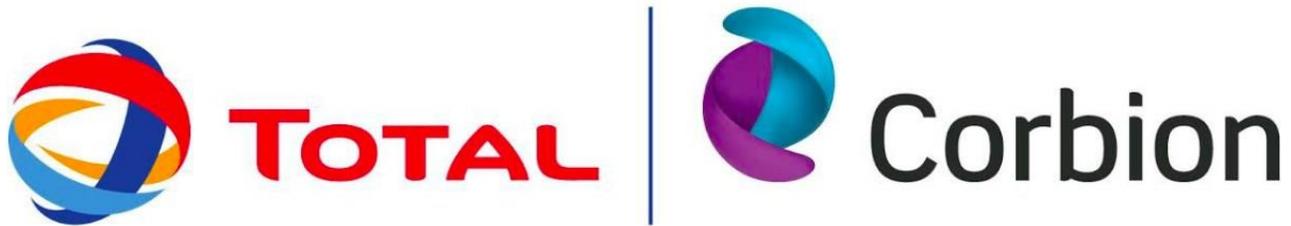


Polylactic acid

## Major producers for polylactic acid



USA, 140 kt plant



Thailand, 75 kt plant

# Biodegradable and biobased polymers and applications

## Overview part 2

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### ■ Biodegradable and biobased polymers

- Polylactic acid (PLA)
- Polyhydroxyalkanoates (PHA)
- Polyester / Compounds

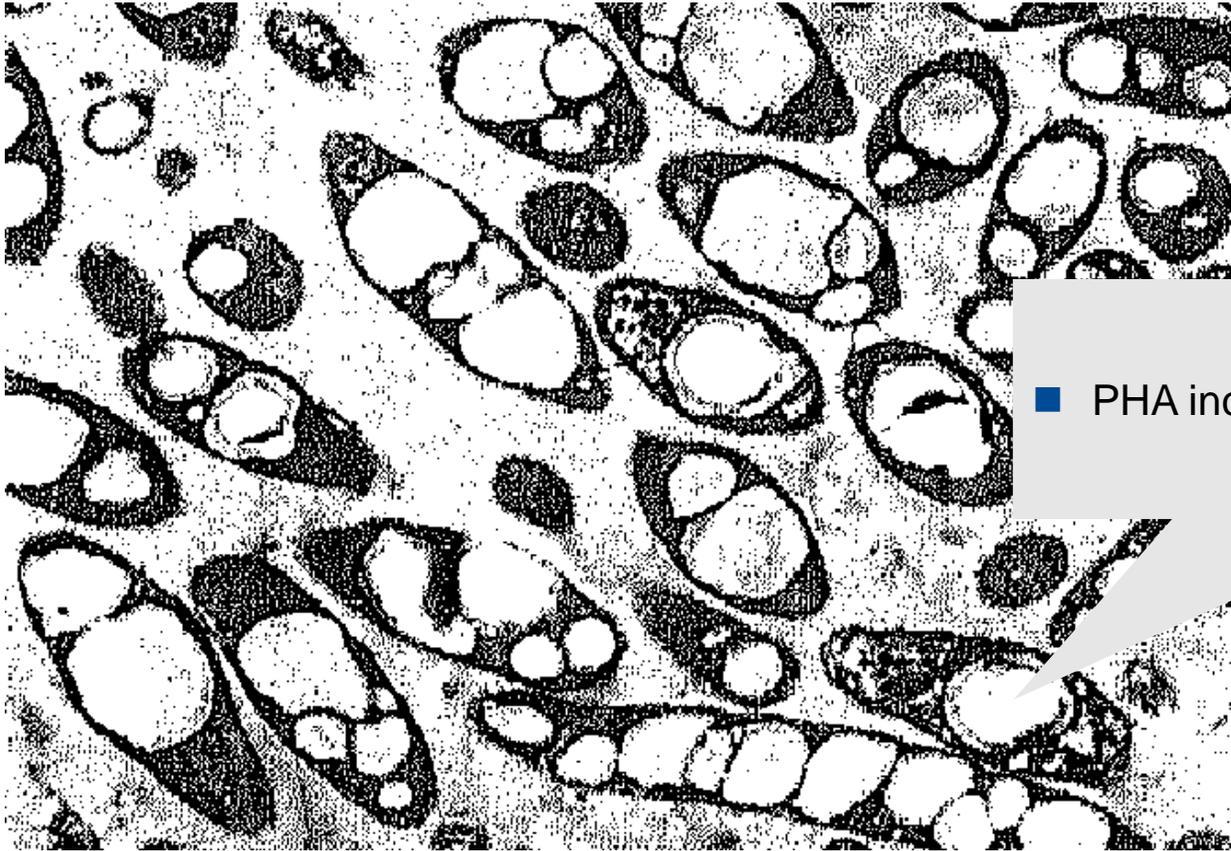
### ■ Applications of biodegradable and biobased polymers

- Market, legislation, capacities & application overview and public perception
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- Packaging

### ■ Durable and biobased polymers

---

## Biodegradable Polymers – PHA in *E. coli*



- PHA incorporated into the bacterial cell

# Biodegradable Polymers – PHA-History and actual developments

## Bacteria

- ICI (“Biopol”) - terminated
- Different start-up companies (e.g. Metabolix)
- Chemical companies: **Kaneka (Japan) – pilot production plant**

## University research

- Prof. Sinskey (MIT Boston, USA)
- Prof. Lee (Korea)
- Prof. Wittholt (ETH Zürich, Switzerland)
- Prof. Steinbüchel (Münster, Germany)

## Plants

- Monsanto
  - Canola (plastic + oil), terminated (e.g. purification problems)
- Metabolix
  - switch grass (terminated)

## Biodegradable Polymers – PHA production process

### Fermentation

Production of biomass/  
Accumulation of PHA  
polymer



### Recovery

Non solvent  
base

Solvent  
based



### Processing

Drying  
Extrusion  
Comminution

## Biodegradable Polymers – Polyhydroxyalkanoates

### Conditions of accumulation of PHA

- Excess carbon source
- growth is limited by depletion of
  - Nitrogen
  - Oxygen
  - Phosphorus, sulfur or magnesium

### Accumulation of PHA within the cell

## Criteria for selecting of production organism

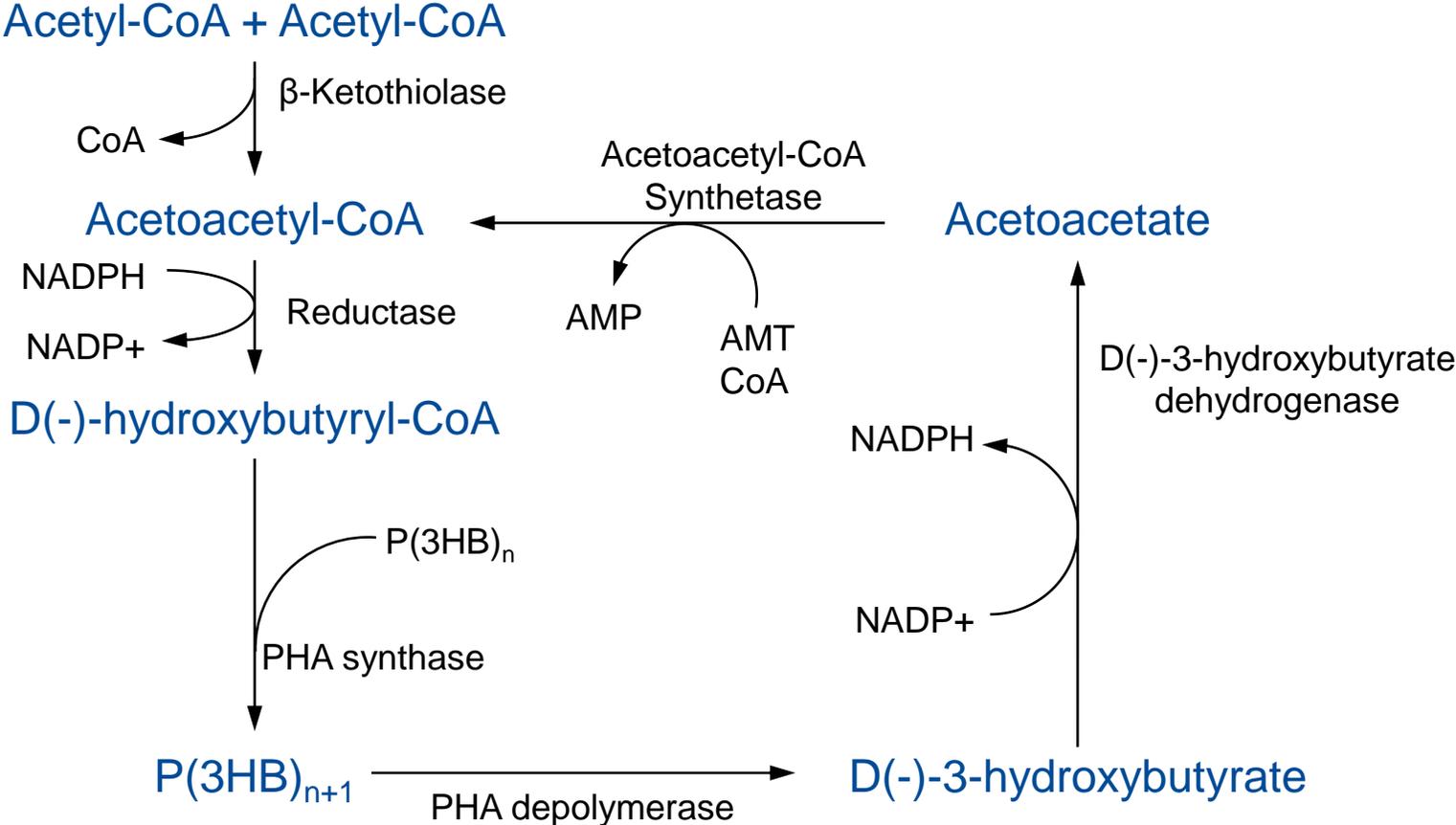
- Growth rate
- Polymer synthesis rate
- Maximum concentration of PHA
- Yield of PHA (g Polymer/ g substrate)
- Cell structure (→ downstream processing)
- Tools for Metabolic Engineering
- Oxygen demand

## Biodegradable Polymers – PHA production organisms

Organism	Natural producer	PHA-production	Comments
<i>Ralstonia eutropha</i> ( <i>Alcaligenes eutrophus</i> )	yes	stationary phase	ICI, Biopol
<i>Alcaligenes latus</i>	yes	during growth	sucrose as growth substrate
<i>Escherichia coli</i> (GMO)	no	during growth	<ul style="list-style-type: none"> <li>– no degradation pathway</li> <li>– overexpression FtsZ (cell division protein)</li> </ul>

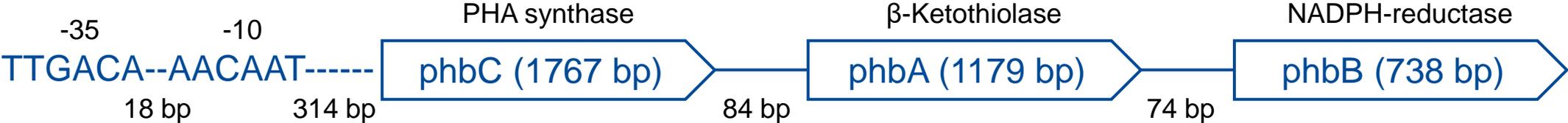
# Polyhydroxyalkanoates

## Biodegradable Polymers – PHA-Synthesis



# Polyhydroxyalkanoates

## Biodegradable Polymers – PHA gene organization



**Fig. 3.** Organization of polyhydroxyalkanoate biosynthesis operon in *Alcaligenes eutrophus*. <sup>131.164</sup>

from Lee, 1996

## Polyhydroxyalkanoates

# Biodegradable Polymers – PHA producers

Strain	PHA	Substrate	Time	Cell concentration [g/l]	PHA [g/l]	PHA content [%]	Productivity [g/l-1h-1]
<i>Ralstonia eutropha</i>	P(3HB)	Glucose	50	164	121	76	2,42 <sup>1</sup>
	P(3HB/3HV)	Glucose + Propionic acid	46	158	117	74	2,55 <sup>2</sup>
<i>Alcaligenes latus</i>	P(3HB)	Sucrose	20	111,7	98,7	88	4,94 <sup>3</sup>
<i>E. coli</i> (GMO)	P(3HB)	Glucose	49	204,3	157,7	77	3,2 <sup>4</sup>

1 = Kim et al. 1994a

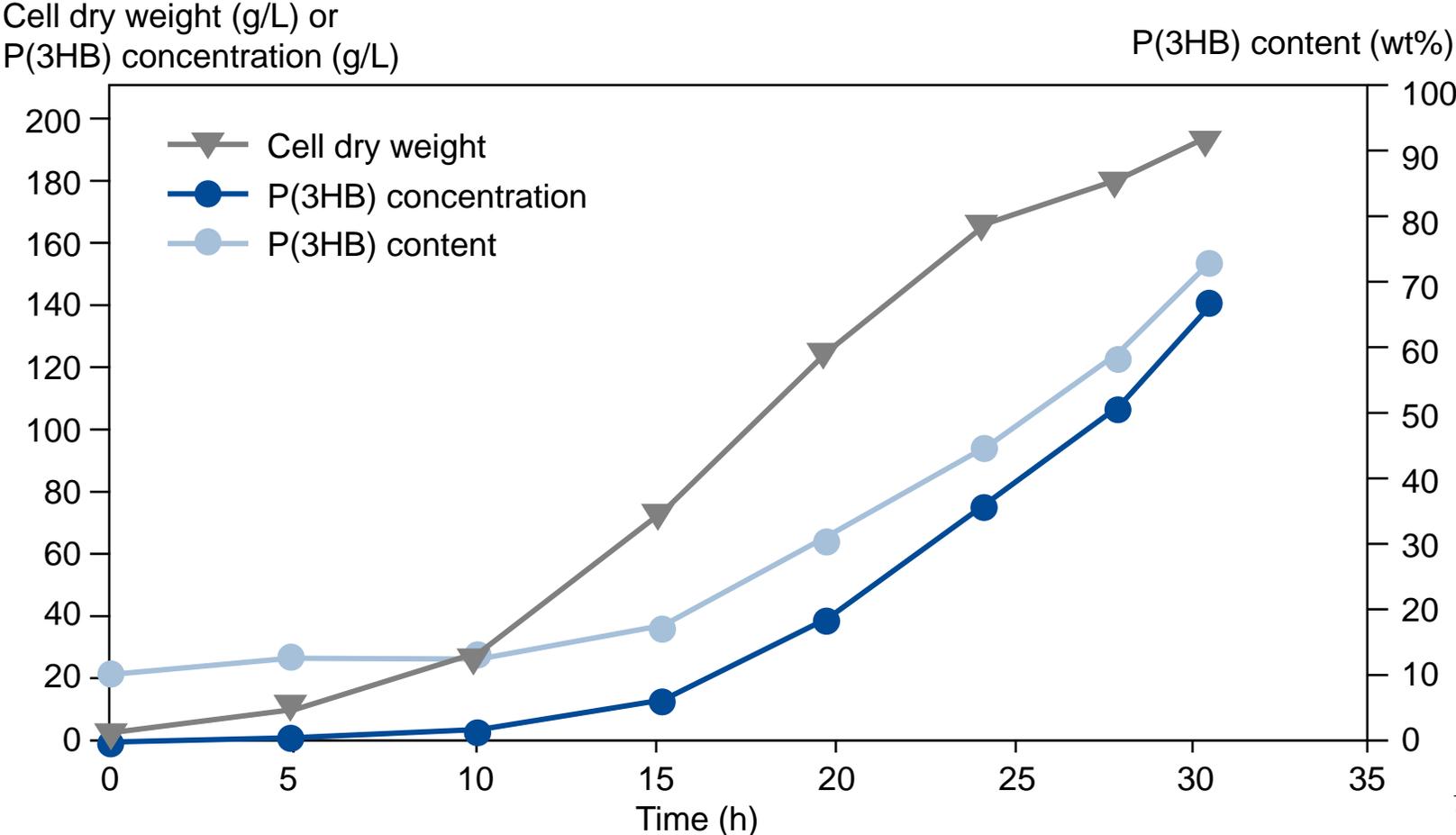
2 = Kim et al 1994b

3 = Wang & Lee 1997a

4 = Wang & Lee 1997b

# Polyhydroxyalkanoates

## Biodegradable Polymers – PHB (Poly (3-hydroxybutyrate)) synthesis in E. coli



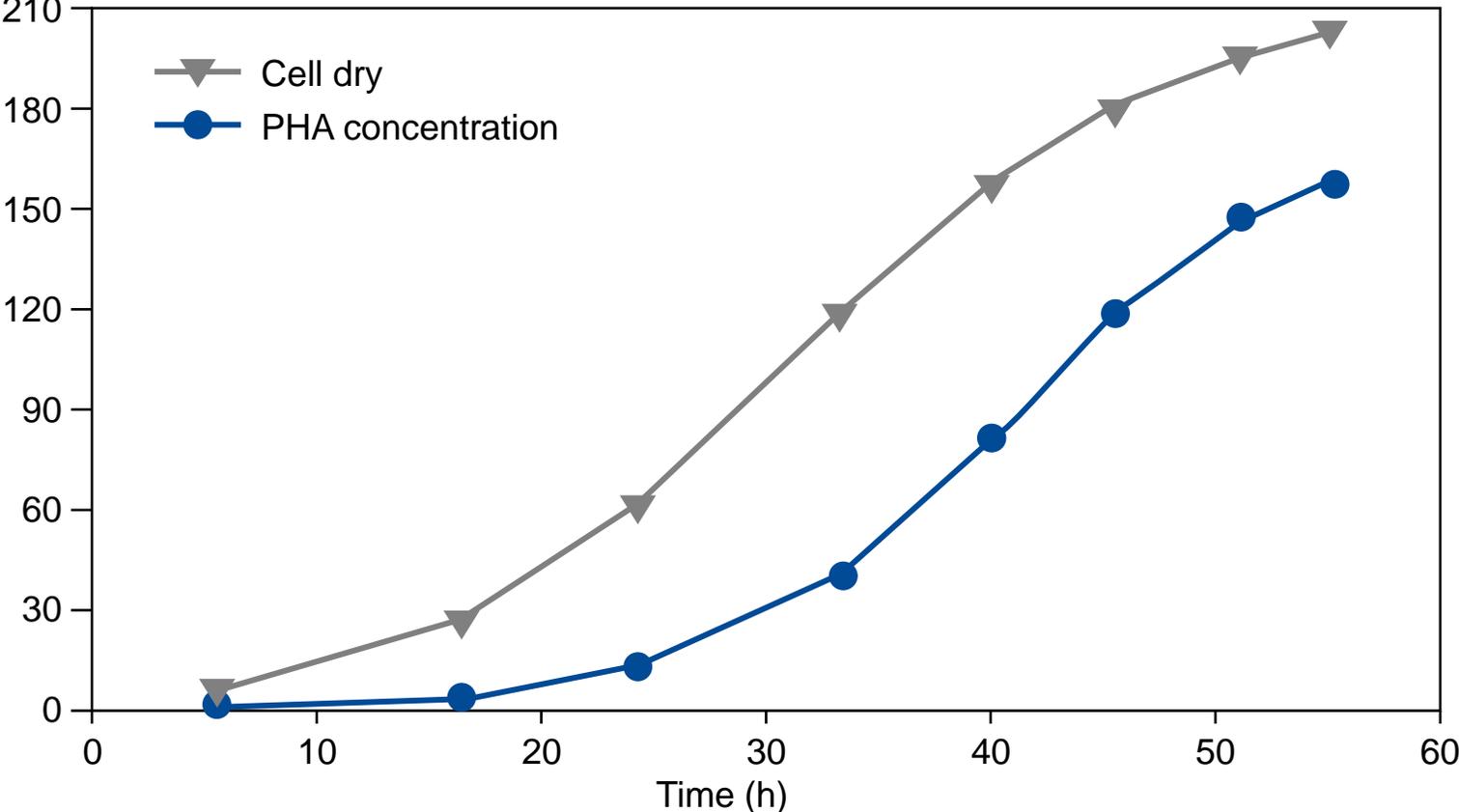
from Lee & Choi, 2001



# Polyhydroxyalkanoates

## Biodegradable Polymers – P(HB/V) (Poly (3-hydroxybutyrate-3-hydroxyvalerate)) synthesis in E. coli

Cell dry weight (g/L) or  
PHA concentration (g/L)

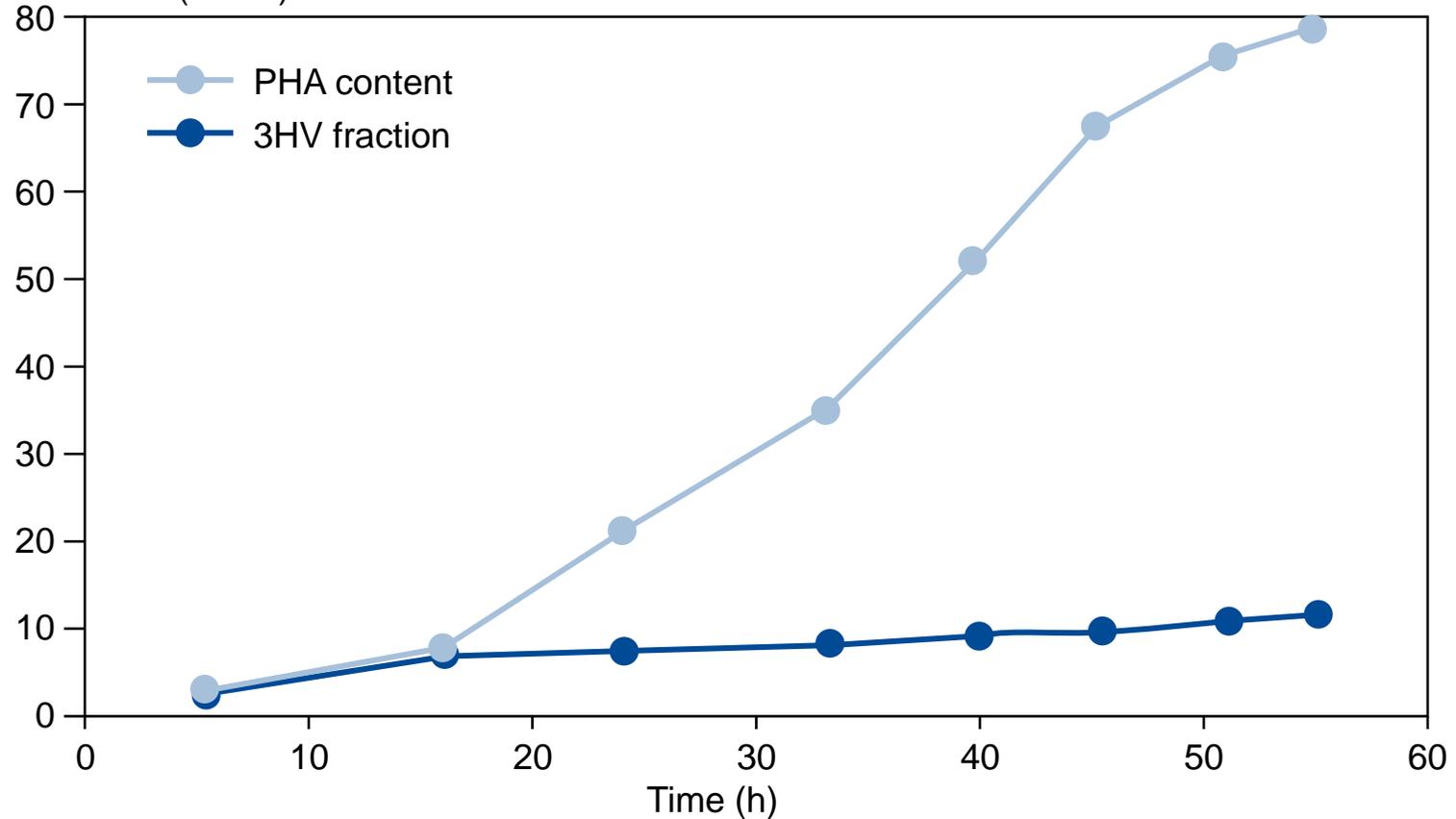


from Lee & Choi, 2001

## Polyhydroxyalkanoates

# Biodegradable Polymers – PHB (Poly (3-hydroxybutyrate)) synthesis in E. coli

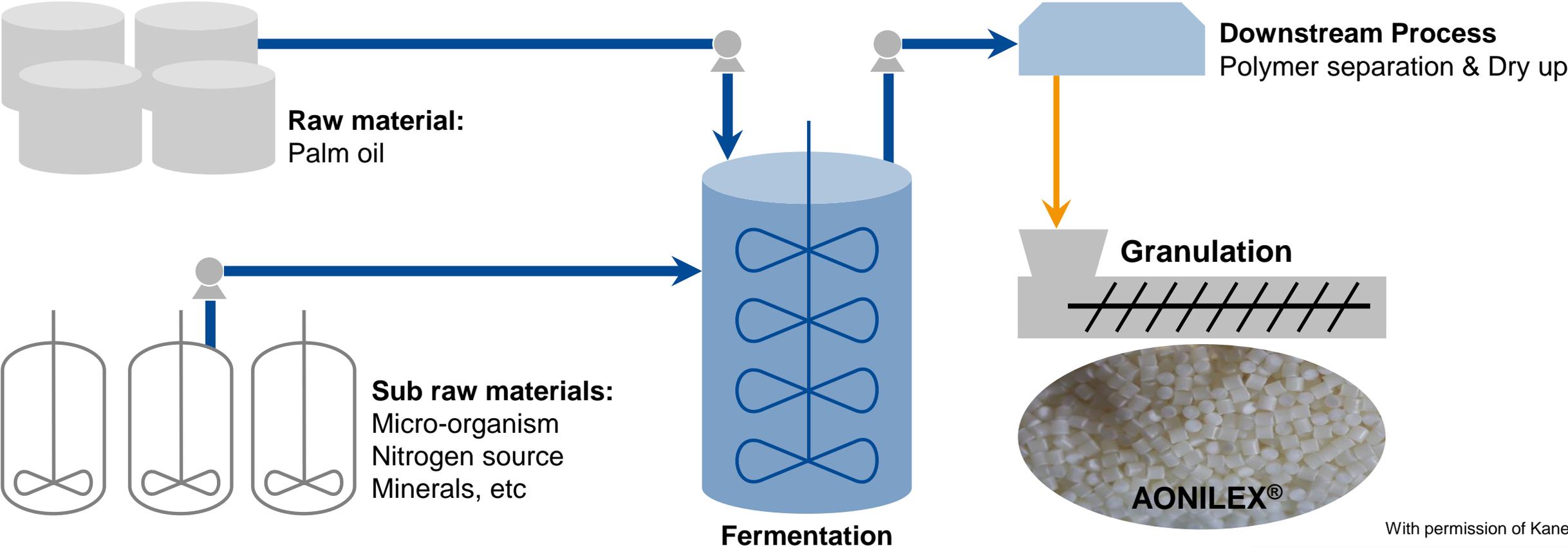
PHA content (wt%) or  
3HV fraction (mol%)



from Lee & Choi, 2001

# Polyhydroxyalkanoates

## Scheme of AONILEX<sup>®</sup> Production Process

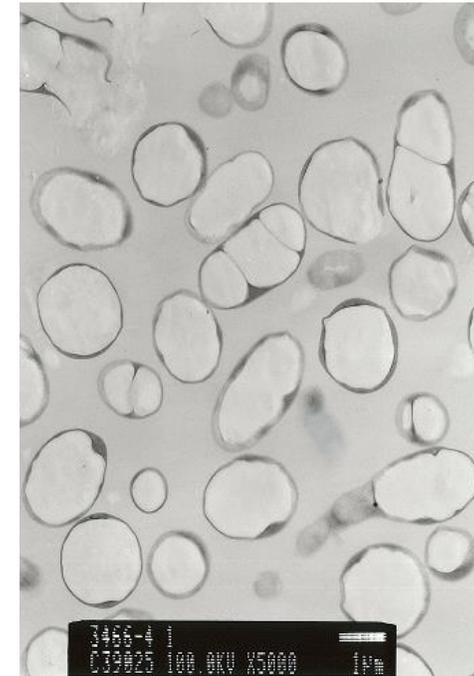
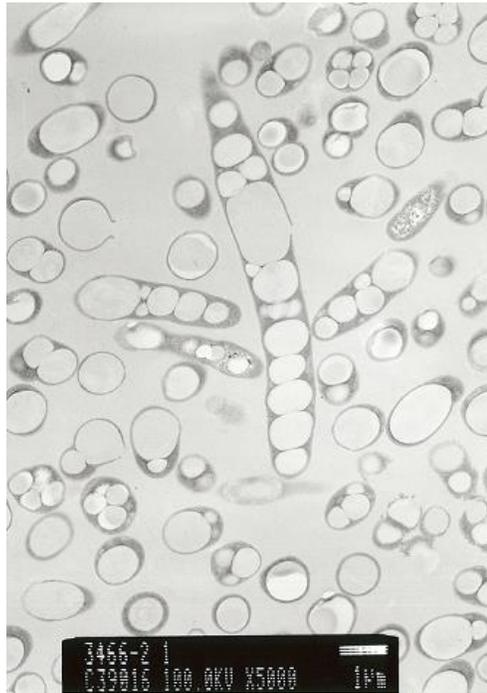
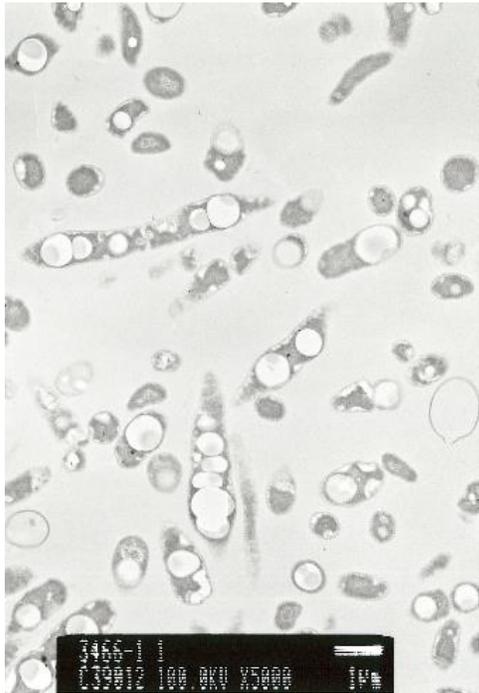


With permission of Kaneka

# Polyhydroxyalkanoates AONILEX<sup>®</sup> Polymer Accumulation during the culture

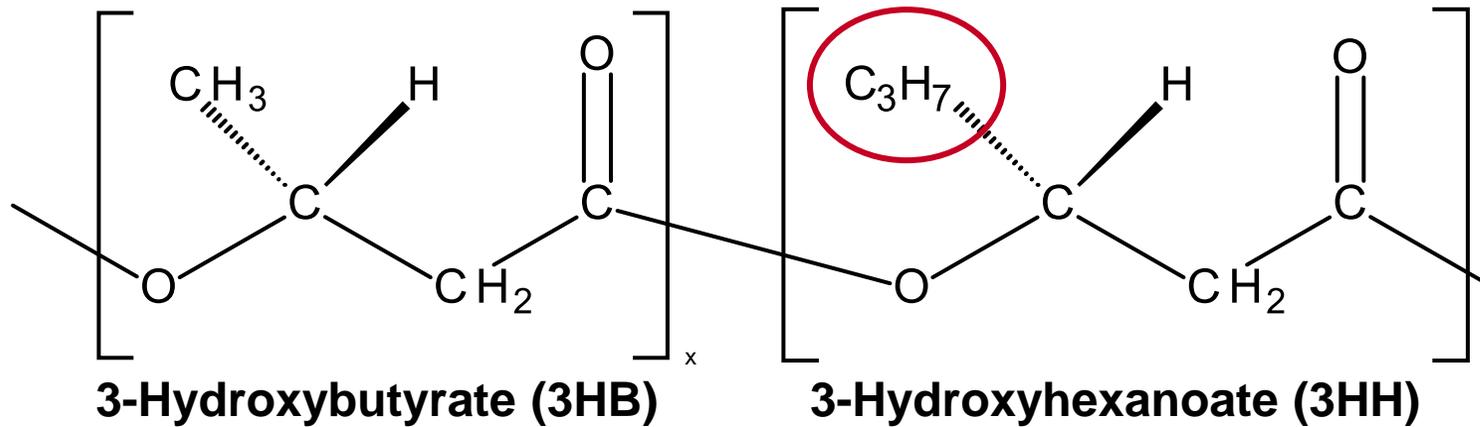
# Kaneka

The Dreamology Company  
— Make your dreams come true —



Culture Time

With permission of Kaneka



- Copolymer of 3-hydroxybutyrate and 3-hydroxyhexanoate
  - Average Mw : 500,000 - 700,000
  - Composition ratio of rigid grade is 3HB/3HH = 93/7, (X131A)
  - Composition ratio of semi-rigid grade is 3HB/3HH = 89/11, (X151A)

With permission of Kaneka

Polyhydroxyalkanoates  
AONILEX<sup>®</sup> Production in Hyogo, Japan

**Kaneka**

The Dreamology Company  
— Make your dreams come true —



**2011:**  
Start production  
(capacity 1,000 MT/year)

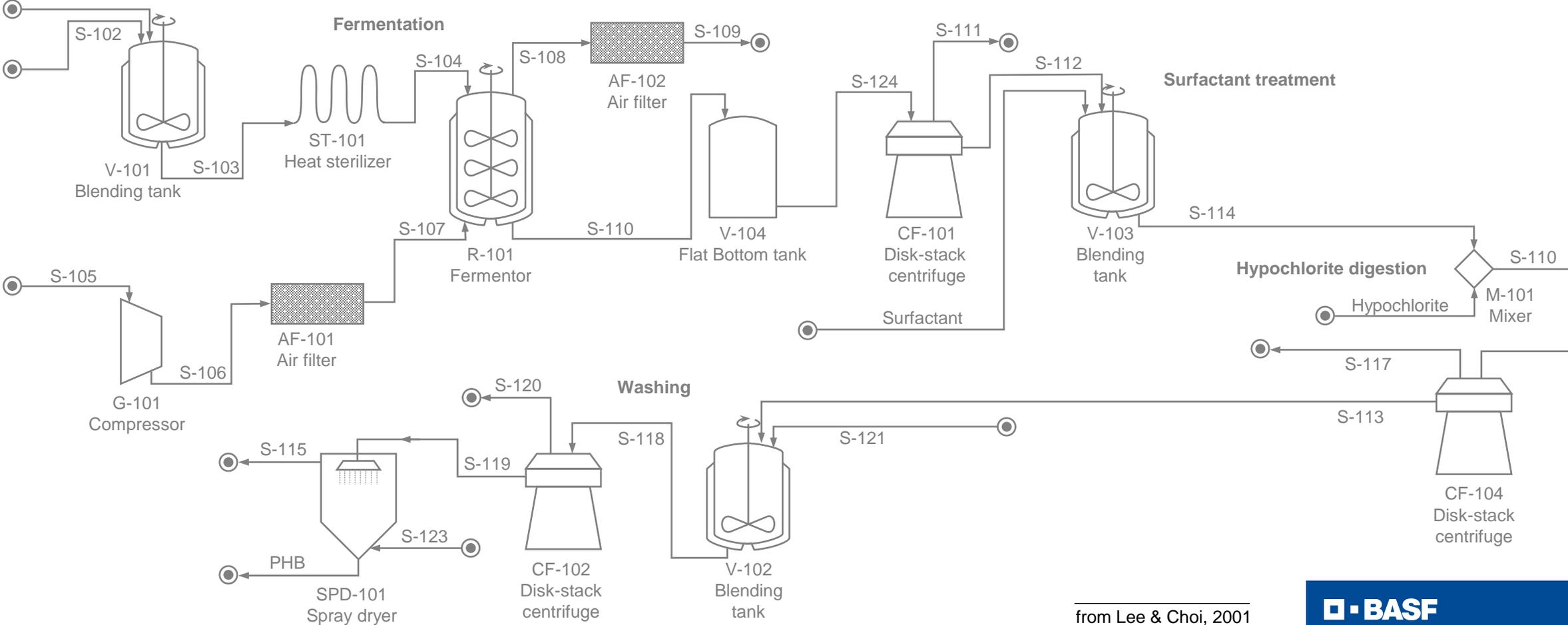
With permission of Kaneka

**BASF**  
We create chemistry

# Polyhydroxyalkanoates

## Biodegradable Polymers – PHA production process:

### Surfactant hypochlorite digestion



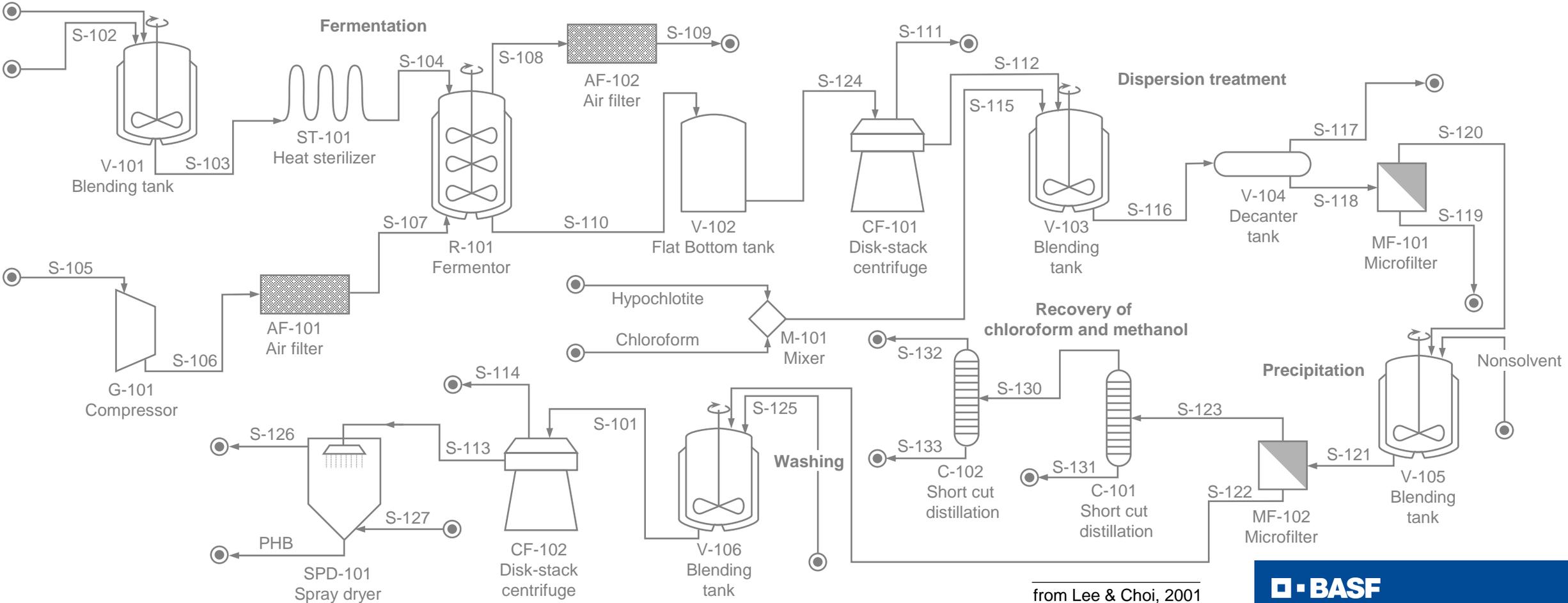
from Lee & Choi, 2001



# Polyhydroxyalkanoates

## Biodegradable Polymers – PHA production process:

### Solvent based purification



from Lee & Choi, 2001



# Comparison of polymer properties of PLA and PHA

	PLA (Standard)	PHA
<b>Advantage</b>	<ul style="list-style-type: none"><li>■ Transparency</li><li>■ Stiffness/tensile strength</li><li>■ Good price position</li><li>■ World scale production capacity</li></ul>	<ul style="list-style-type: none"><li>■ Biodegradable under all conditions</li></ul>
<b>Limitations so far</b>	<ul style="list-style-type: none"><li>■ Heat stability in applications of standard PLA; special grades with higher stability</li><li>■ Hygroscopic material</li></ul>	<ul style="list-style-type: none"><li>■ Relative high price position vs. other alternatives</li><li>■ Thermostability in processing?</li></ul>
<b>Challenges</b>	<ul style="list-style-type: none"><li>■ Biodegradability limited to industrial composting</li></ul>	<ul style="list-style-type: none"><li>■ Purification</li><li>■ World scale production</li></ul>
<b>Major applications &amp; targets</b>	<ul style="list-style-type: none"><li>■ Different packaging applications e.g. transparent stiff packaging applications</li></ul>	<ul style="list-style-type: none"><li>■ Different applications: e.g. bags, packaging</li></ul>

# Biodegradable and biobased polymers and applications

## Overview part 2

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### ■ Biodegradable and biobased polymers

- Polylactic acid (PLA)
- Polyhydroxyalkanoates (PHA)
- Polyester / Compounds

### ■ Applications of biodegradable and biobased polymers

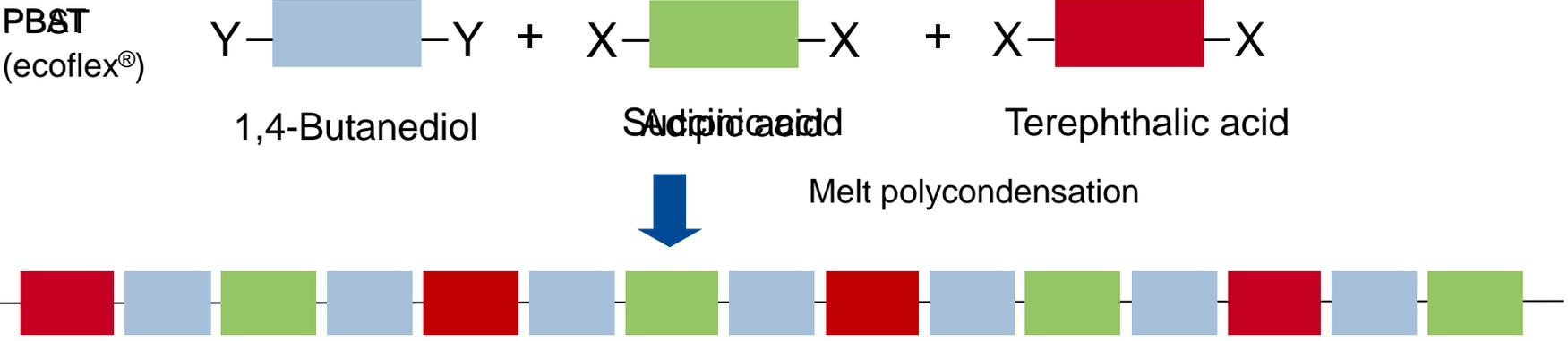
- Market, legislation, capacities & application overview and public perception
- Agricultural mulch film
- Organic waste management
- Packaging

### ■ Durable and biobased polymers

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# Polyester / Compounds

## ecoflex<sup>®</sup> as modular system



- ecoflex<sup>®</sup> is a random aliphatic-aromatic copolyester
- Access to biobased ecoflex<sup>®</sup> variants possible (e.g. by replacing adipic acid with biobased succinic acid)
- Each monomer change influences melting point, tensile strength, crystallization speed & biodegradation behavior

Change of monomer and monomers composition results in new properties

# ecoflex<sup>®</sup> and ecovio<sup>®</sup> of BASF: continuous technology and market development



**1993:** start R&D

**1998:** market introduction ecoflex<sup>®</sup>

**2006:** market introduction ecovio<sup>®</sup>

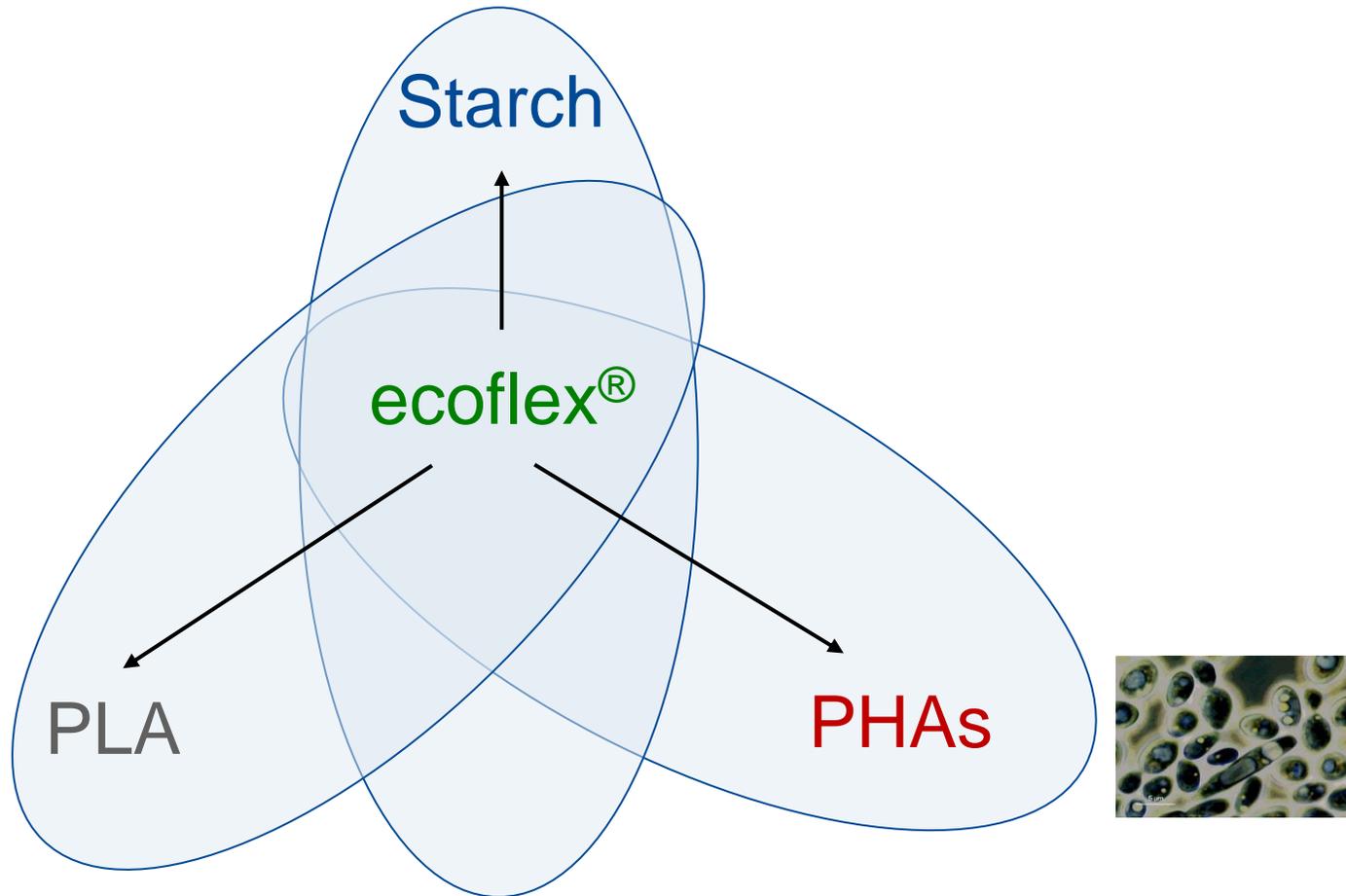
**Since 2007:** continuous development of ecoflex<sup>®</sup> and ecovio<sup>®</sup> portfolio with new applications and increased biobased content

**2010:** startup of the new single-purpose capacity extension in Ludwigshafen (Germany). Total capacity: 14 kta → 74 kta

**Since 2011:** Fundamental research for understanding of biodegradability

Continuous R&D to improve existing products, develop new applications and enlarge biodegradability understanding

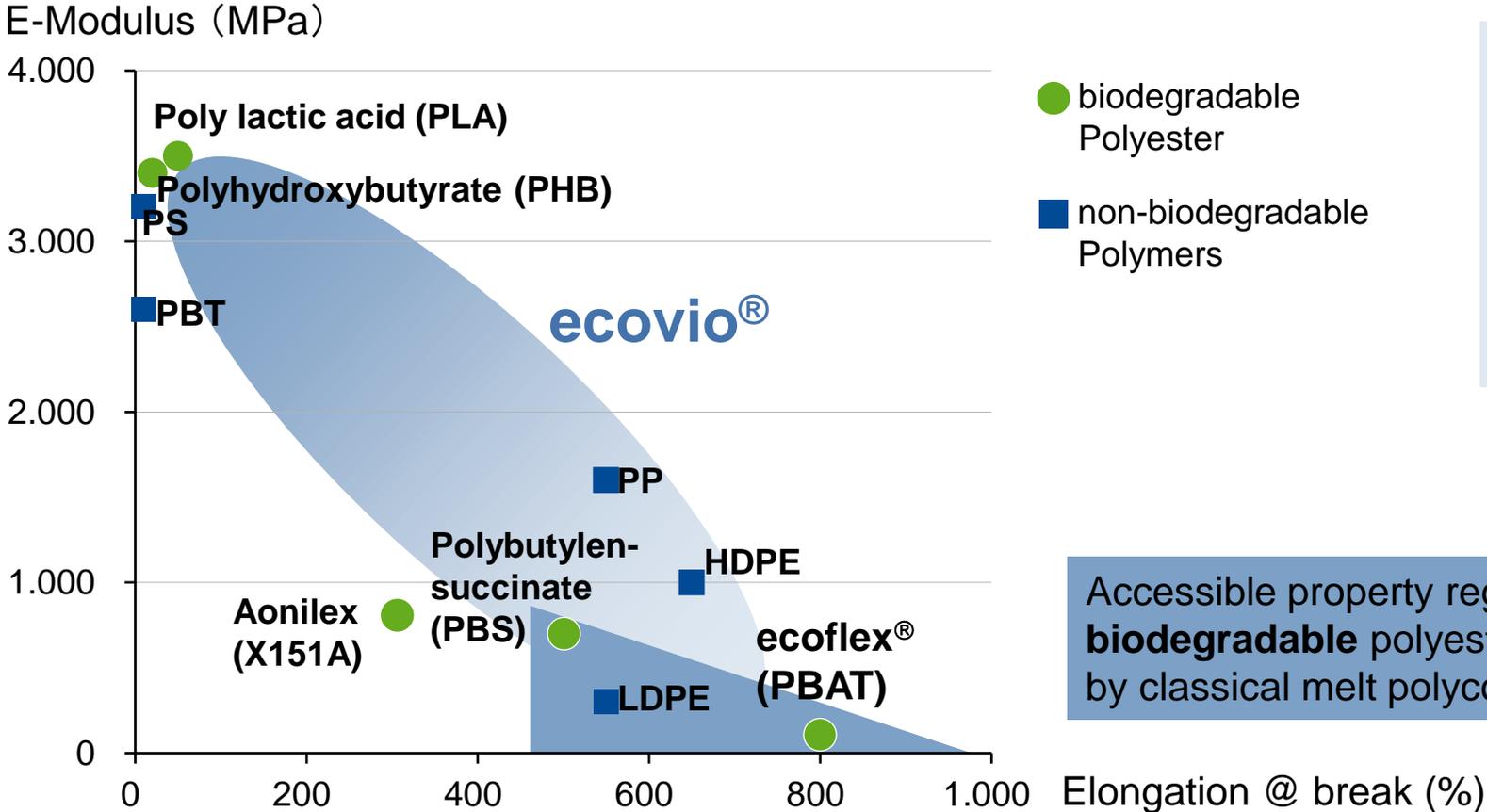
# Compounds of ecoflex<sup>®</sup> and other polymers (starch, PLA, PHA) results in different property profiles



→ ecoflex<sup>®</sup> is an excellent partner and enabler for other biopolymers to produce compounds with different property profiles

# Polyester / Compounds

## ecovio<sup>®</sup> compounds to enable a broad property profile



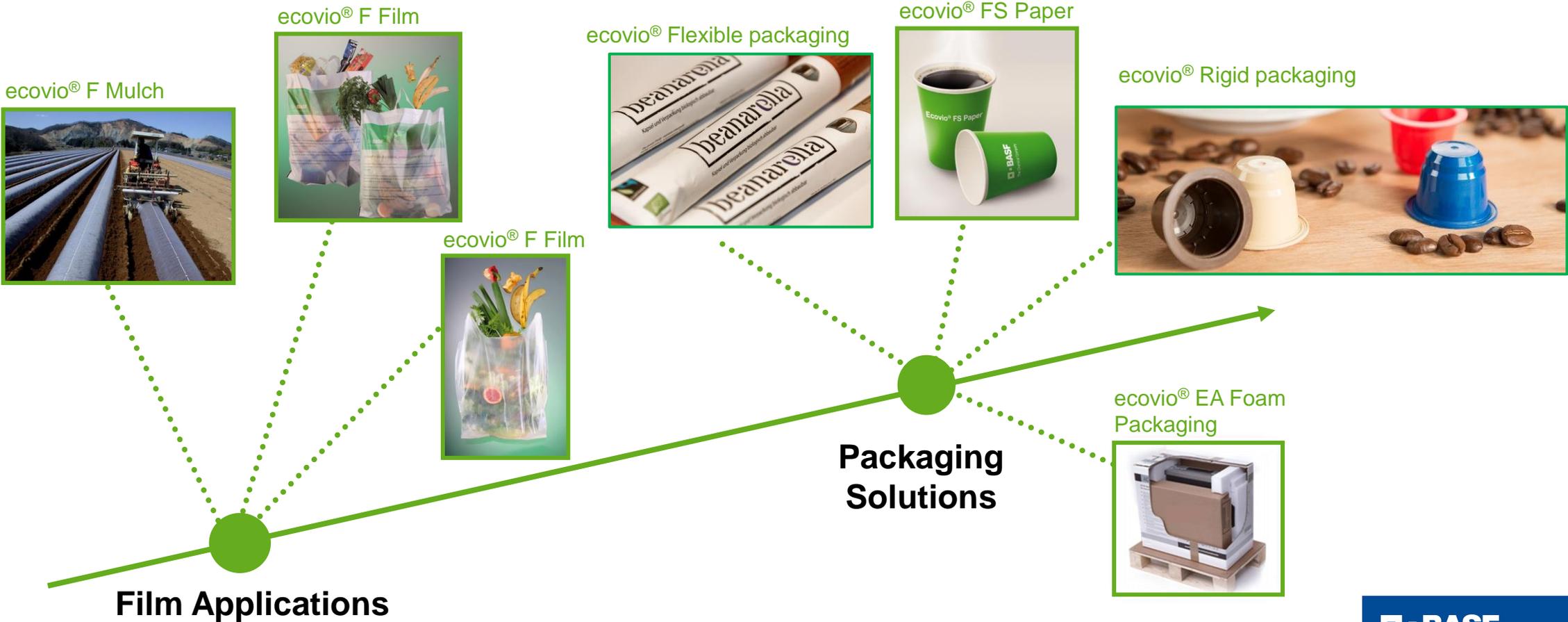
→ Compounds needed for broader property range

→ ecovio<sup>®</sup> is the trade name for BASF's ecoflex<sup>®</sup> based compounds (e.g. with PLA)

Accessible property region for **biodegradable** polyesters made by classical melt polycondensation

Polyester / Compounds

# BASF provides biodegradable and biobased polymer solutions for bags, packaging and agro applications



## Overview part 2

---

### ■ Biodegradable and biobased polymers

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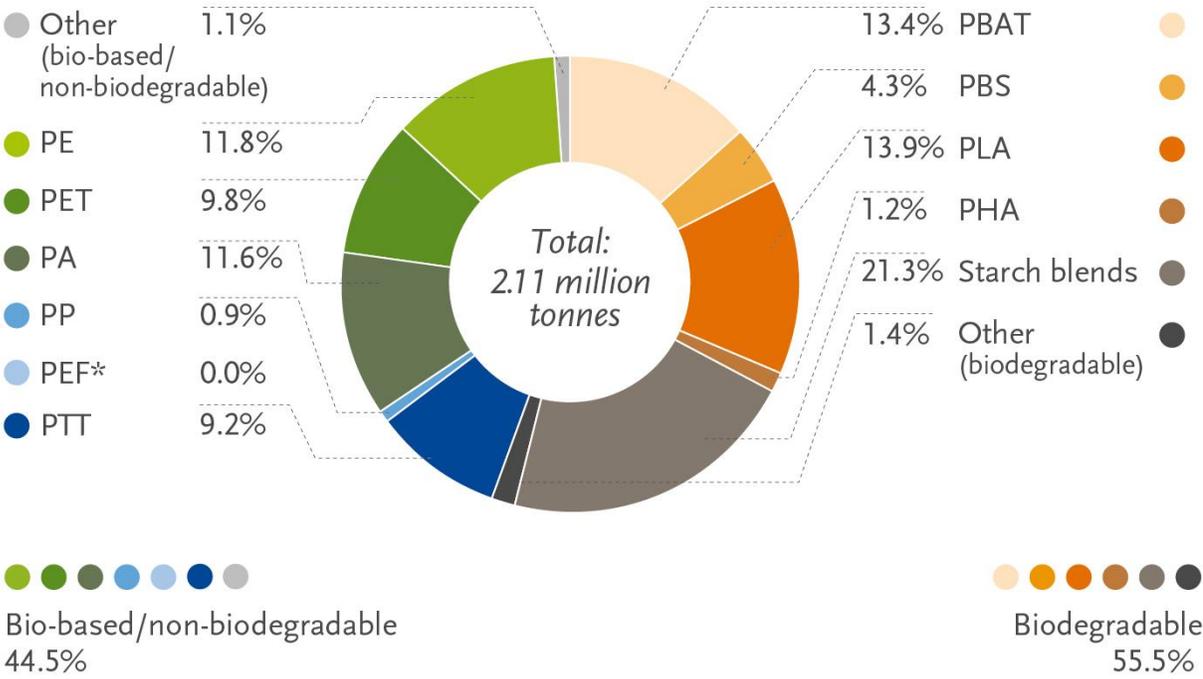
### ■ Durable and biobased polymers

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# Market, capacities and applications

## Overview production capacities

*Global production capacities of bioplastics 2019  
(by material type)*



\*PEF is currently in development and predicted to be available in commercial scale in 2023.

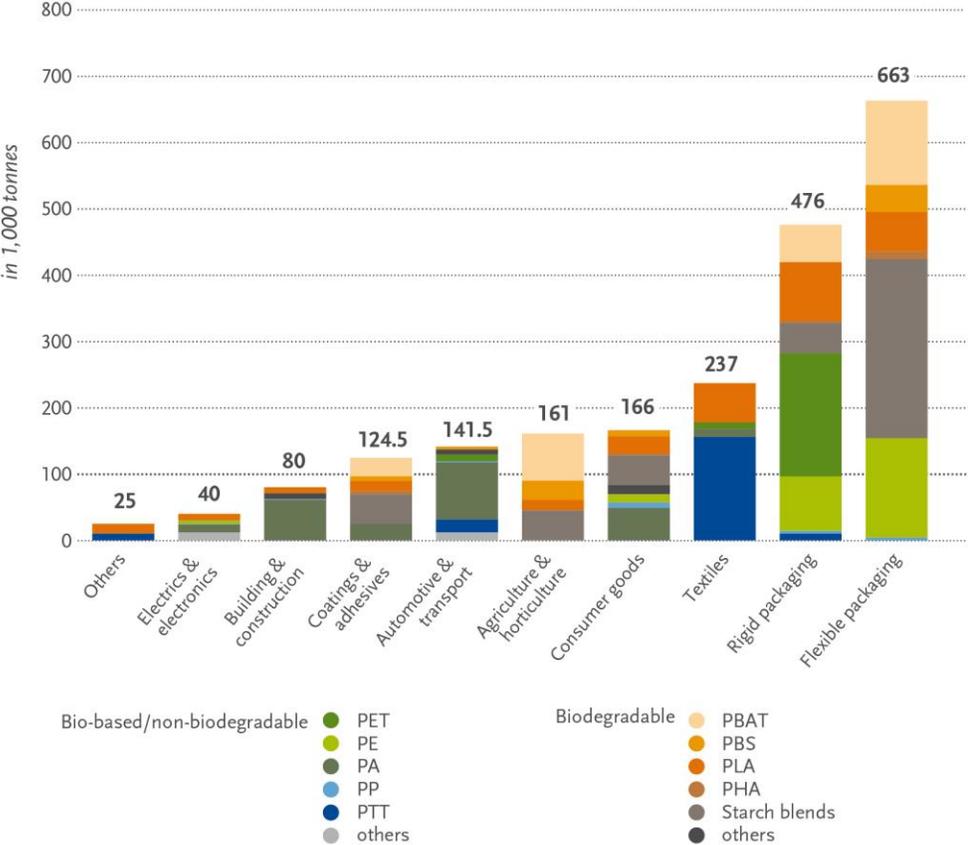
Source: European Bioplastics, nova-Institute (2019)  
 More information: [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market) and [www.bio-based.eu/markets](http://www.bio-based.eu/markets)



# Market, capacities and applications

## Overview market segments

Global production capacities of bioplastics 2019 (by market segment)



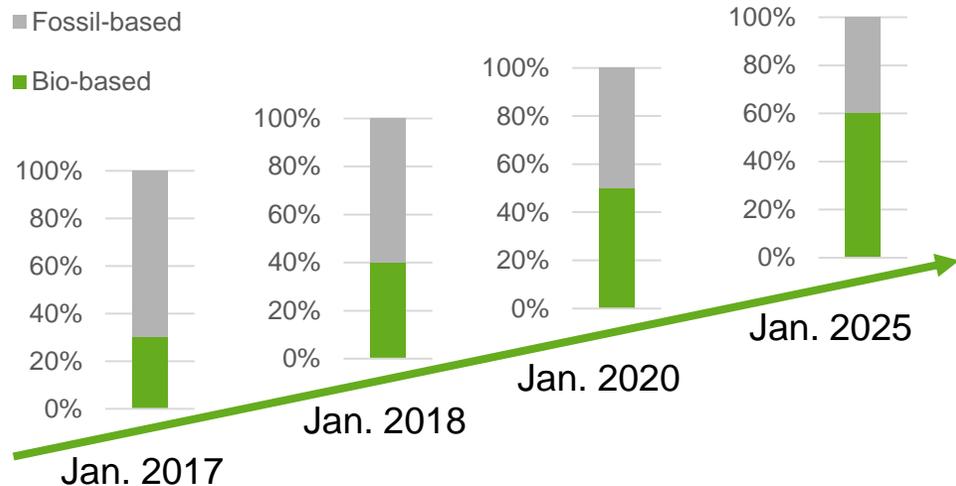
Source: European Bioplastics, nova-Institute (2019). More information: [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market) and [www.bio-based.eu/markets](http://www.bio-based.eu/markets)

# Recent single-use bag bans exempt compostable & bio-based solutions

- With effect of January 2017 the **French** plastic shopping bag ban (<50 µm) will be extended to single-use plastic packaging bags
- Home compostable & bio-based fruit & vegetable bags are exempted
- Oxo-degradable plastic packaging is banned
  
- **Italy** intends to ban plastic fruit & vegetable bags
- Industrial compostable & bio-based bags are exempted
- Existing shopping bag legislation remains unchanged



Increasing bio-based content requirements, e.g. for fruit & vegetable bags in France:



## Public perception of biodegradable and biobased polymers

### Coca-Cola Joins Race for 100% Biobased PET Bottle

Biokunststoffe sind auf dem richtigen Weg  
Umweltbundesamt-Studie bescheinigt  
Biokunststoffen großes Potential

Berlin, 11. Oktober 2012. Eine aktuelle Studie des Instituts für Energie- und Umweltforschung Heidelberg (ifeu-Institut) im Auftrag des Umweltbundesamt (UBA) kommt zu einem positiven Ausblick für die Biokunststoffbranche: Die Umweltwirkungsprofile vieler Biokunststoffe hätten sich seit Ihrer Erstentwicklung stark verbessert und es bestünden weiterhin beträchtliche Optimierungspotentiale. Gesamtökologisch stünden Biokunststoffe heute mindestens auf einer Stufe mit konventionellen Kunststoffen. (European Bioplastics)

„Verbrauchertäuschung von Aldi und Rewe mit angeblich kompostierbaren Einkaufstüten“ (DUH)

Danone führt Verbraucher mit Werbung für Joghurtbecher aus Biokunststoff in die Irre (DUH)

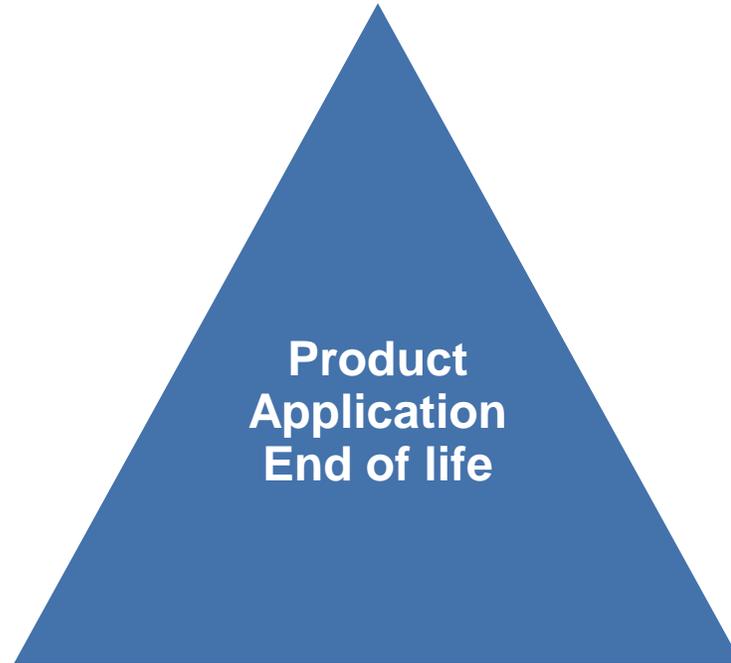
Nur ein Schein von Grün  
Der Markt für Biokunststoffe wächst rasant. Doch die Ökobilanz ist durchwachsen. Die intensive Bewirtschaftung belastet die Äcker (die Zeit)

Very different public perception of value and sustainability benefits of biodegradable and biobased materials

Market, capacities and applications

For Life cycle assessment (LCA) precise definition from raw materials basis via material & application until end of life is needed

**Raw material**  
(e.g. origin of material and resulting impacts)



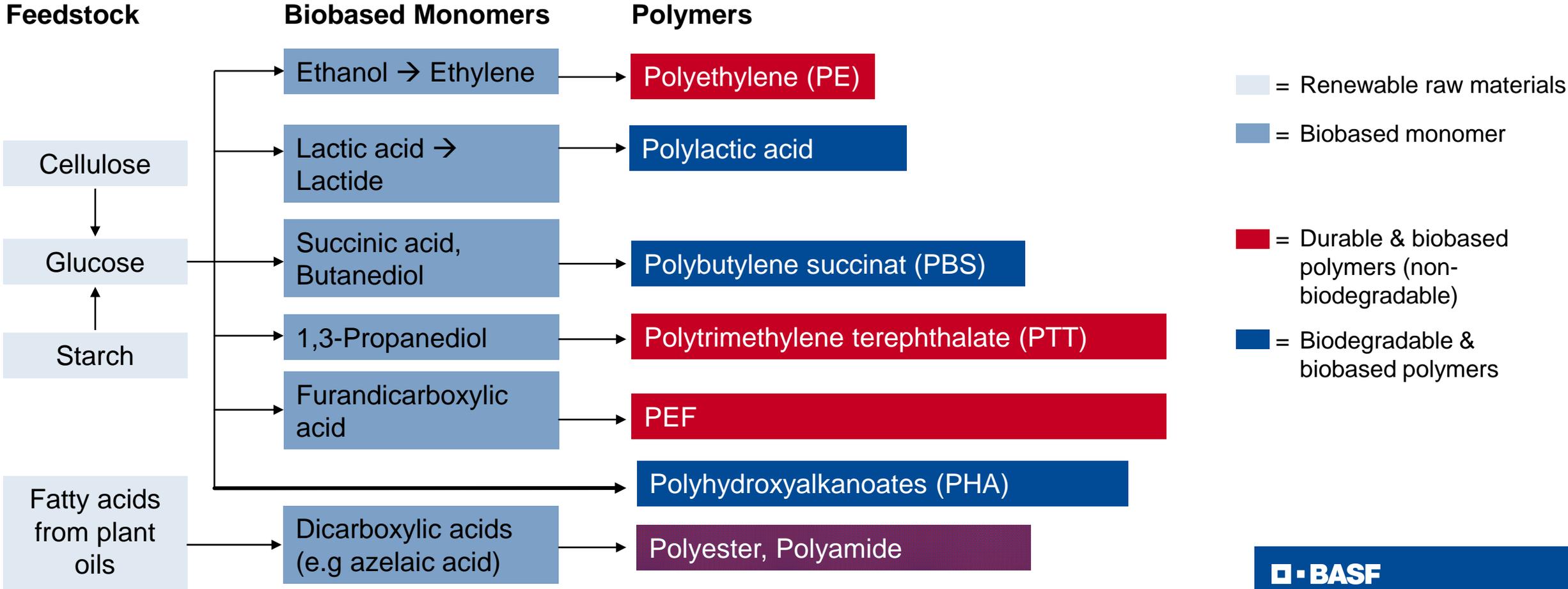
**End of life**  
(environmental effects of utilization esp. realistic end of life impact)

**Polymer & application**  
(production process and use phase)

→ Inclusion of real end of life effects and costs is needed to come to overall sustainability benefit assessment

# Biobased building blocks

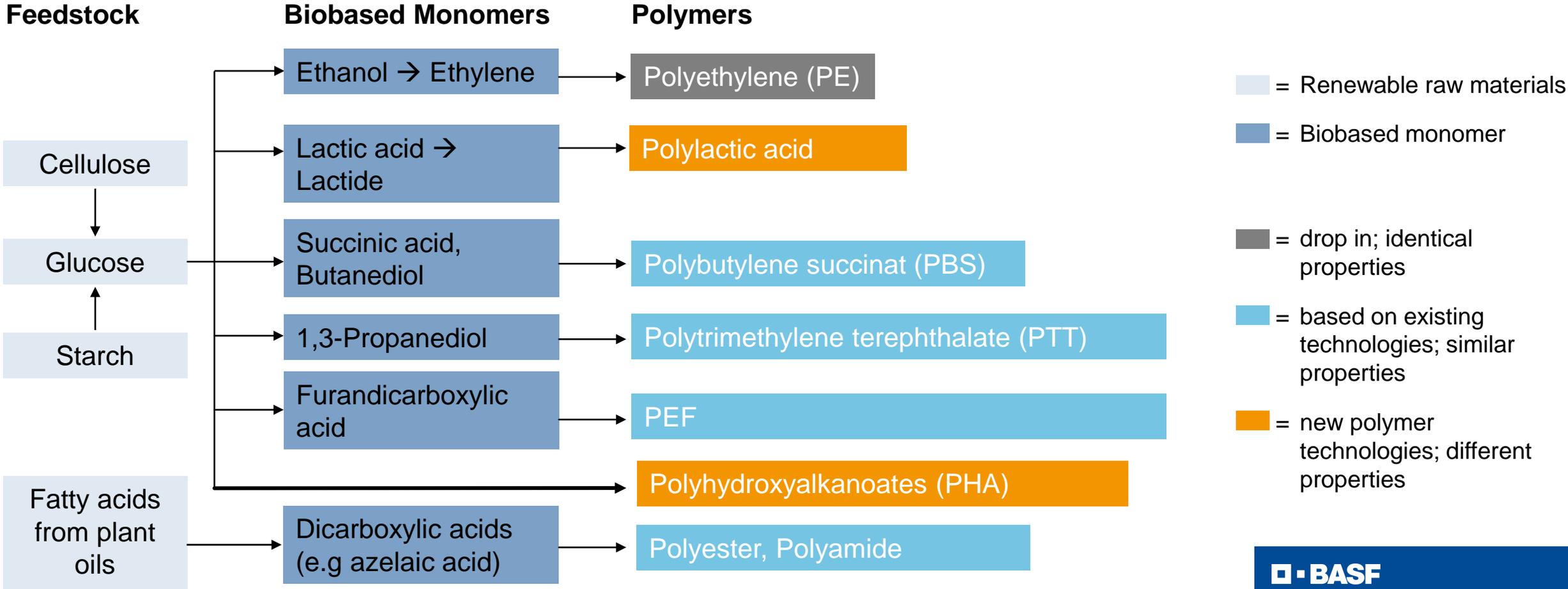
## Biobased building blocks (monomers) and polymers from renewable resources (selected)



- = Renewable raw materials
- = Biobased monomer
- = Durable & biobased polymers (non-biodegradable)
- = Biodegradable & biobased polymers

# Market, capacities and applications

## Biobased building blocks (monomers) and polymers from renewable resources (selected)



- = Renewable raw materials
- = Biobased monomer
- = drop in; identical properties
- = based on existing technologies; similar properties
- = new polymer technologies; different properties

# Market, capacities and applications

## 2006: only one world scale production plant for biopolymers is existing

	Lab scale	Pilot scale	Production capacity in 2006	
Poly lactide (PLA)			70 kt	 
Polyhydroxyalkanoates (PHA)			2 kt	
Polybutylene succinate (PBS)			12 kt	 
ecoflex®			15 kt	 
Polytrimethylene terephthalate (PTT)			fossil based ≈ 150kt, biobased < 10 kt	
Biobased PE				
Biobased PP				
Biobased PA			mainly PA 11: ≈15 kt	 

# Market, capacities and applications

## 2020: Significant scale up and capacity increase for biopolymers, but still a niche vs. fossil benchmarks

	Lab scale	Pilot scale	Estimated production capacity in 2020			Estimated trend until 2025	
Poly lactide (PLA)			270 kt	 	  	↗	
Polyhydroxyalkanoates (PHA)		~ 10 kt		 		3 Chinese with small capacities	↗
Polybutylene succinate (PBS)		~ 40 kt		  		3 Chinese with capacities < 2kt	↗
ecoflex® (PBAT, PBSeT)			300 kt	 	 	3 Chinese with capacities < 10kt	↗
Polytrimethylene terephthalate (PTT)		biobased ~ 50 kt					→
Biobased Polyethylene			220 kt			100% biobased (Ethanol based)   30% biobased (renewable cracker feed)	↗
Biobased Polypropylene		30% biobased – capacity unknown				30% biobased (renewable cracker feed)	↗
Biobased Polyamides			100–150 kt	 	  	several more	↗



## Overview part 2

---

- Biodegradable and biobased polymers
    - Polylactic acid (PLA)
    - Polyhydroxyalkanoates (PHA)
    - Polyester / Compounds
  - Applications of biodegradable and biobased polymers
    - Market, legislation, capacities & application overview and public perception
    - Agricultural mulch film
    - Organic waste management
    - Packaging
  - Durable and biobased polymers
-

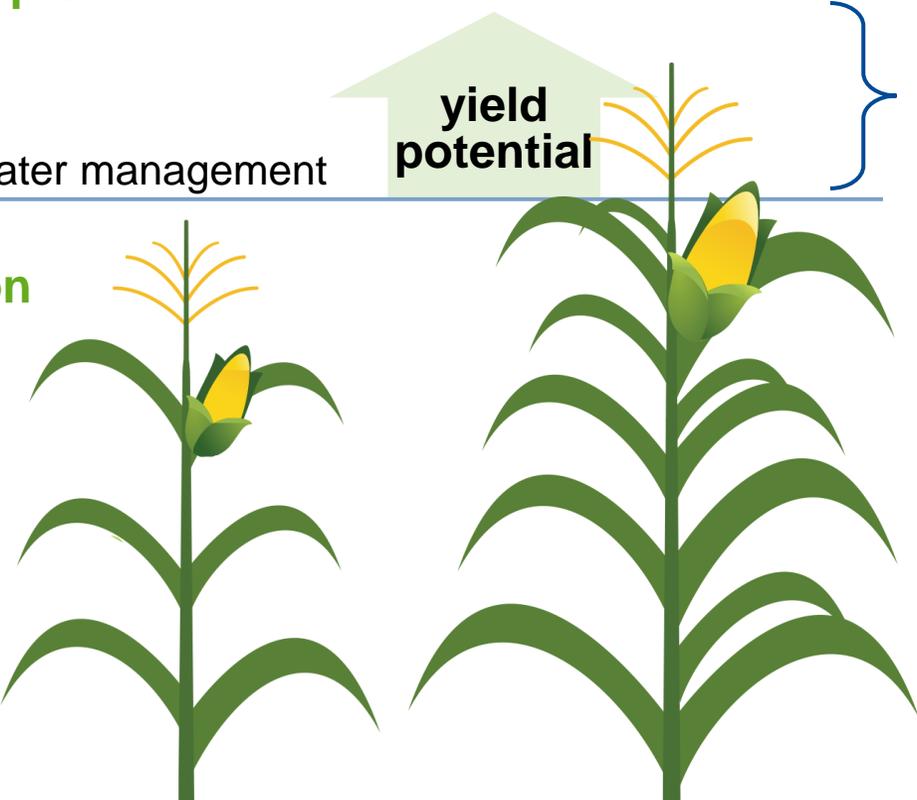
# Crop protection can be achieved with different approaches

## Functional Crop Care

- Plant Health
- Biologicals
- Nutrient and water management

## Crop Protection

- Fungicides
- Insecticides
- Herbicides



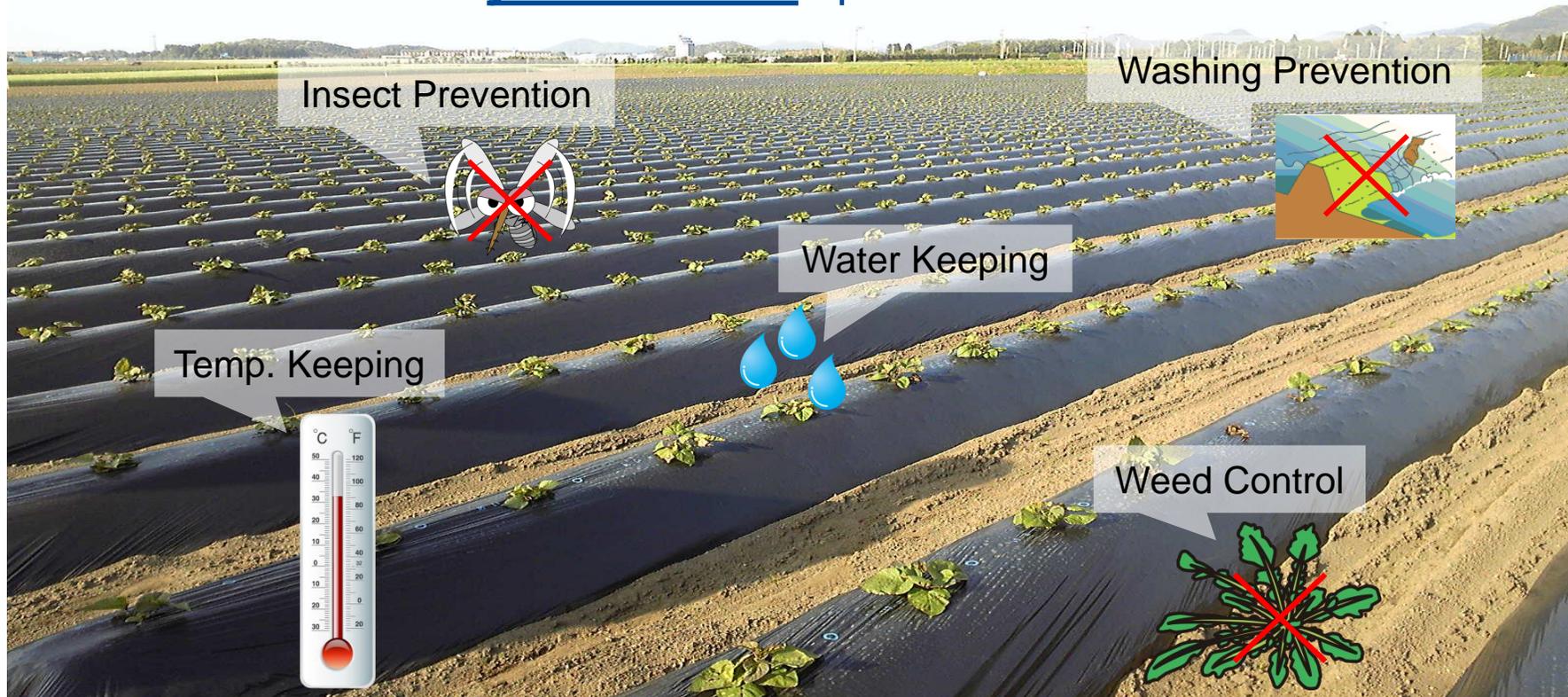
## Abiotic stress is the main driver of yield loss

- Drought
- Heat
- Cold
- Nutrient deficiency
- UV light

## Agricultural mulch film

# Mulch film increase crop yield via different functions

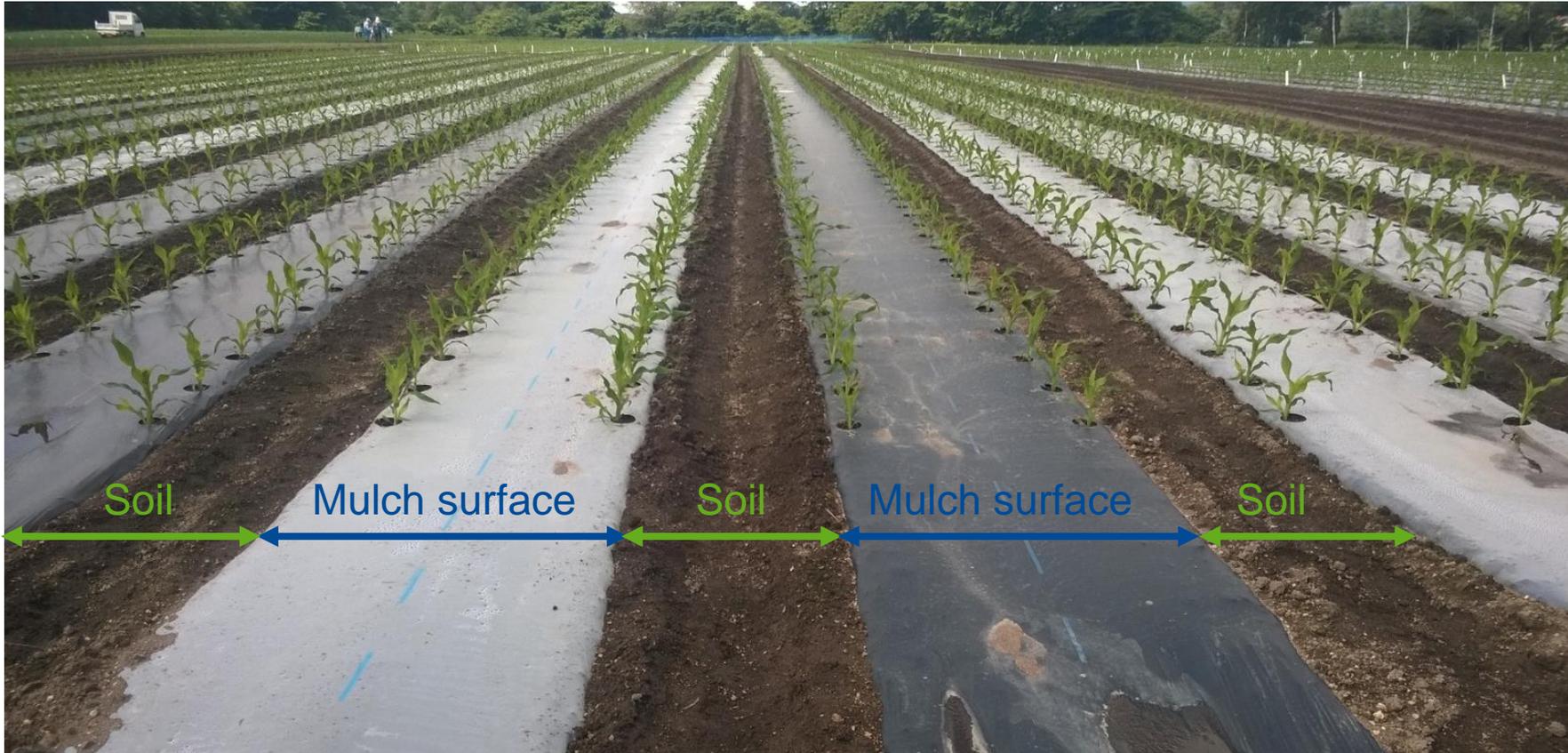
Each function leads to **yield increase** up to 50%.



→ Mulch film is plastic film which is specialized for different crops in agriculture.

# Agricultural mulch film

## Mulch film installation method



→ Surface covered with mulch film strips assumed to be 85% of the total field.









# Agricultural mulch film

## Mulch film usage steps: end of life is the difference between biodegradable polymers (ecovio®) and PE

- Biodegradable mulch film is plowed in the soil
- PE mulch film is recollected



# Agricultural mulch film

## Disposal of agricultural film



Industrial recycling  
(greenhouse film)

Dirt < 5% of weight

Dirt 60-80% of weight (mulch)  
Controlled/uncontrolled  
burning

Dirt > 5% of weight

→ Reduction of operational costs by using biodegradable mulch film

Photos: Universidad de Lleida, 2009

\*Gonzalez (IMIDA), 2012



## Agricultural mulch film

# Used agricultural film: recycling or biodegradation?

Application type	Soil “attachment” rate	Thick-ness	Trucks of virgin film	Trucks to send back used mulch film	Tonnage of “attachment” to carry and eliminate per truck of 25t virgin film
Greenhouse	20%	200μ	1	1.2	5 t
Mulch	70%	25μ	1	3	58 t
Thin mulch	80%	15μ	1	5	100 t

→ Thin films with high soil “attachment” rate

“attachment”: crop residues, weeds, clay, sand, water...

## Agricultural mulch film

# The reality in China: Use of PE mulch film



- Insufficient collection of PE mulch; Soil pollution leads to reduced yield of crops
- Open field burning results in generation of toxic substances

## Agricultural mulch film

To achieve environmental performance thickness of PE film is defined by mechanical requirements for collection

- Biodegradable mulch film: ~12  $\mu\text{m}$  thickness
- Polyethylene mulch film:  $\geq 25 \mu\text{m}$  thickness needed to ensure collection



Film  
Manufacturing

Carriage  
and  
Storage

Installation

Crop  
Development

Plowing  
or  
Collection

Fallow  
Period

Next  
Cropping

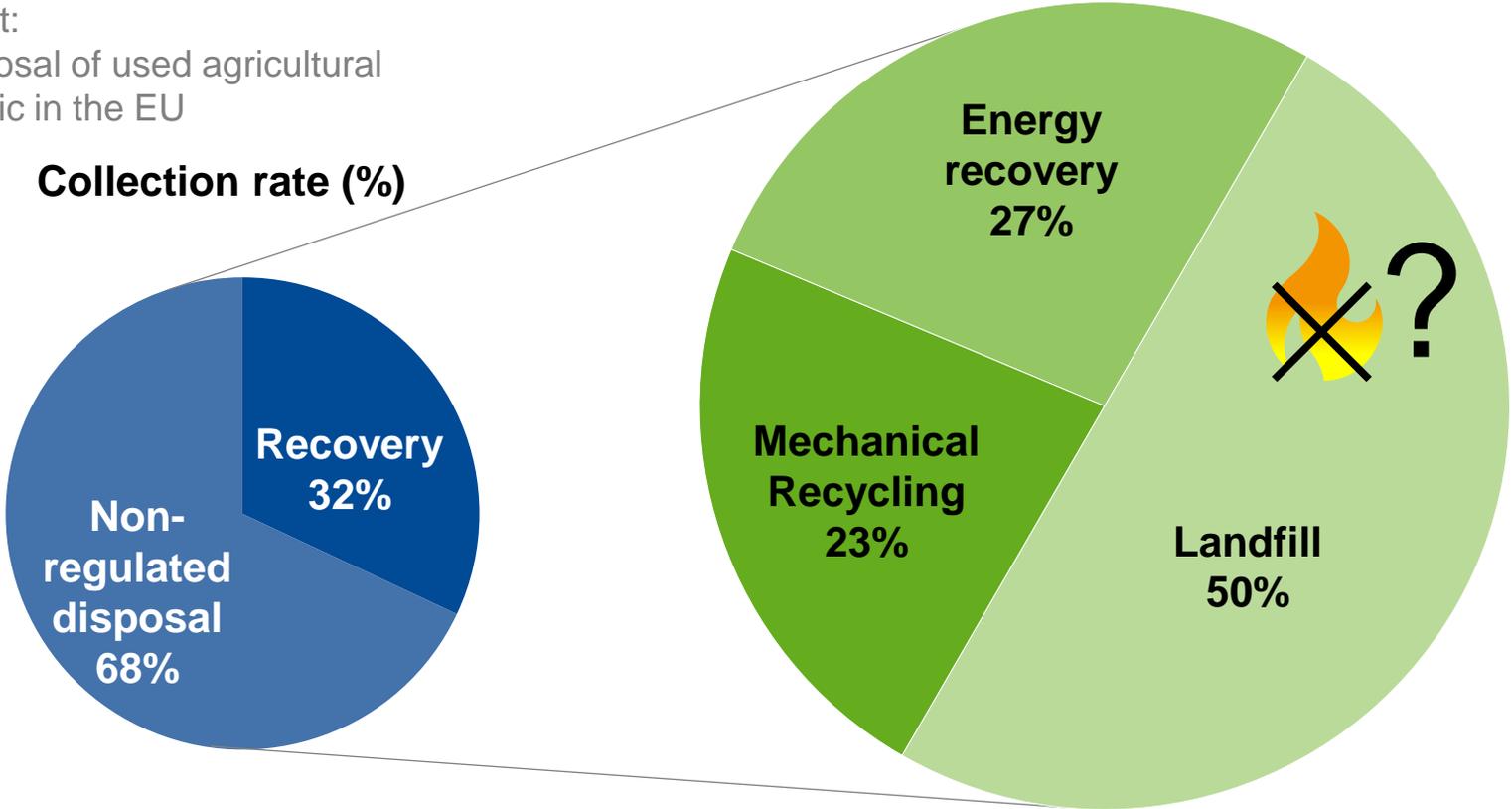
A photograph of a man in a maroon shirt and dark pants, smiling broadly while holding two watermelons. He is standing in a greenhouse with rows of watermelon plants supported by a wooden trellis system. The background shows other workers and more rows of plants, creating a sense of a busy agricultural setting.

# Ecological Benefits of Biodegradable Mulch Film

# Agricultural mulch film

## Estimating the thickness to enable recovery of agricultural film based on the EU example

Chart:  
Disposal of used agricultural plastic in the EU



→ Due to high “attachment rate”, most mulch films are not recycled

Source: APE Europe and EPRO, presented by AMI Consulting, Agricultural Film Conference 2014

# Agricultural mulch film

## The challenge – our motivation



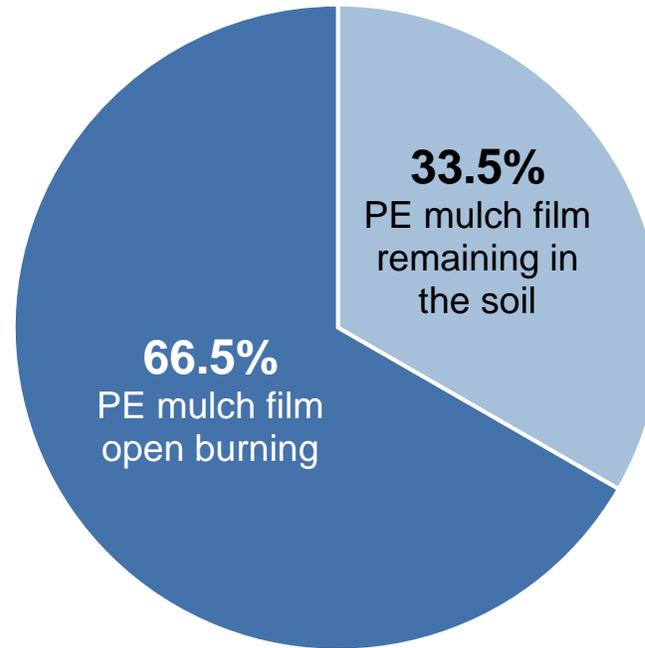
→ Thin mulch film hinders used film collection (e.g. China)

# Agricultural mulch film

## Soil pollution leads to reduced yield



### End-of-Life Assumptions



→ Long term\* use of 10µm PE mulch film results in the expected mean yield decrease of cotton of 8.5% per year

\* Long term describes a period of 15 years or more

Agricultural mulch film

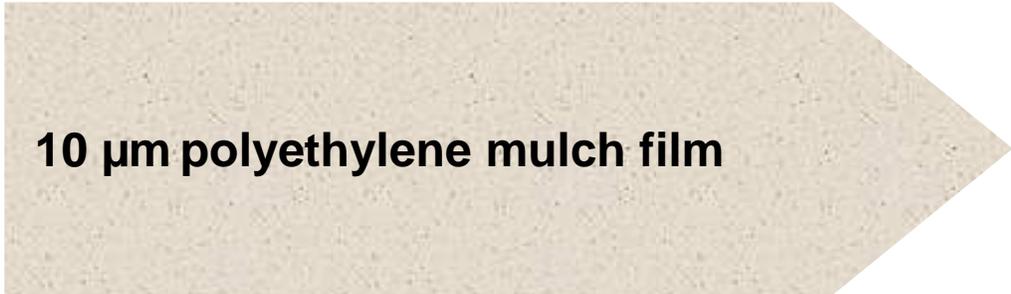
## Comparative study of PE and ecovio<sup>®</sup> mulch film



**Growing 1 tonne  
of raw cotton  
in Xinjiang, China  
by considering an average  
yield decrease over 15 years**

A rectangular sample of 10 µm ecovio mulch film, which has a brown, woven, fabric-like texture. The sample is shaped like a right-pointing arrow.

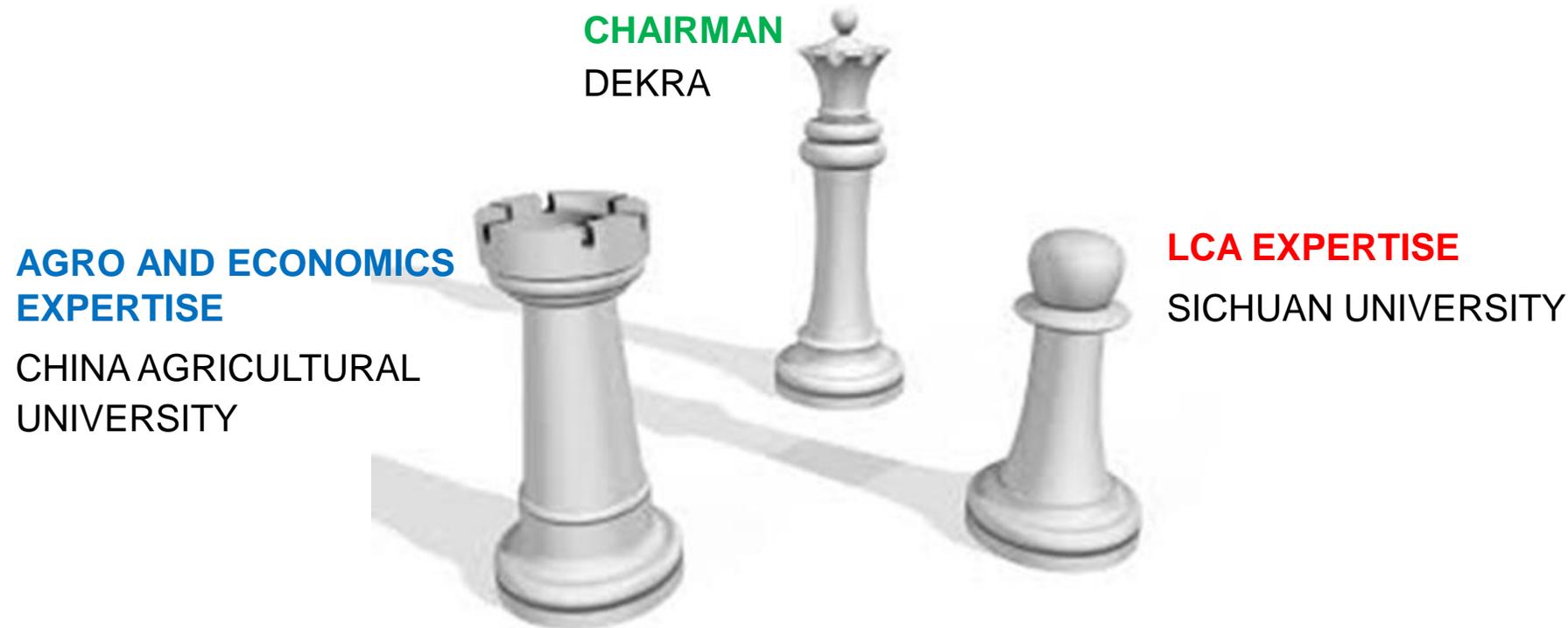
**10 µm ecovio<sup>®</sup> mulch film**

A rectangular sample of 10 µm polyethylene mulch film, which is a smooth, light beige color. The sample is shaped like a right-pointing arrow.

**10 µm polyethylene mulch film**

# Agricultural mulch film

## Critical review panel – key findings



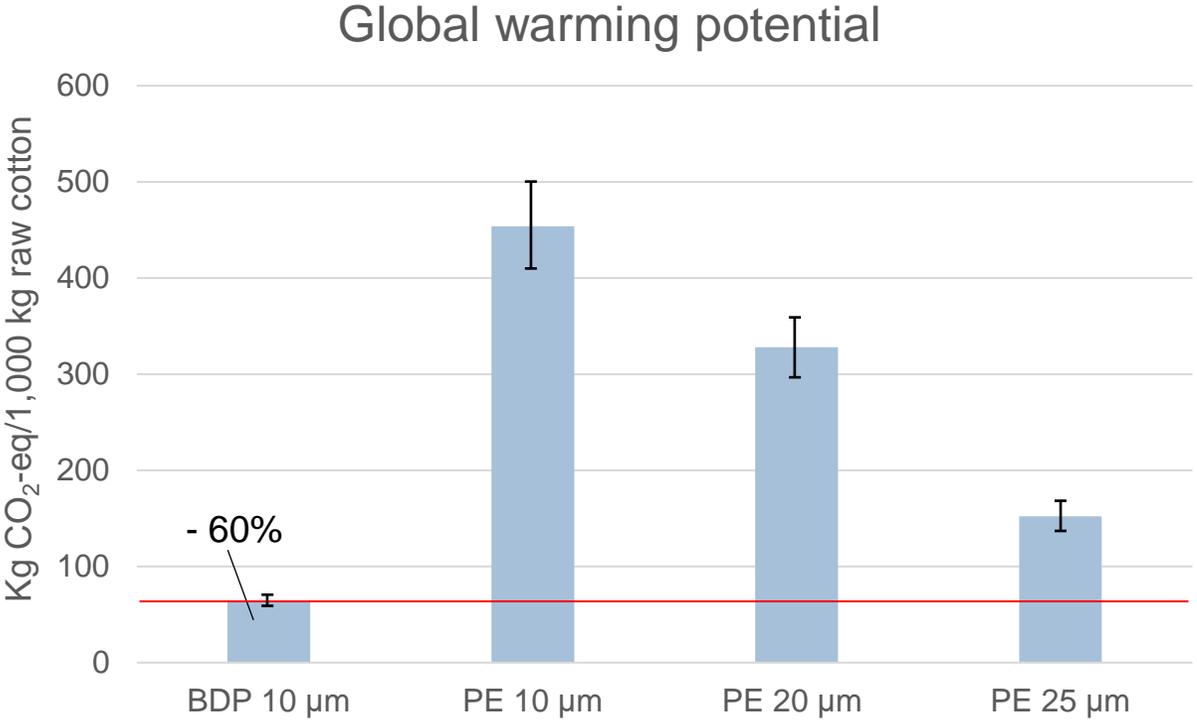
→ Review of the LCA study confirms benefits of biopolymers in every\* environmental dimension

\*Consumptive Water Use, Land Use, Acidification Potential (AP), Abiotic Depletion Potential (ADP), Global Warming Potential (GWP), Photochemical Ozone Creation Potential (POCP), Ozone Depletion Potential (ODP), Eutrophication Potential (EP), Solid Wastes, Cumulative Energy Demand (CED). Toxicity and Social (Illnesses) categories could not be quantified due to very limited data on different air and soil toxic pollutants emitted during open burning of the PE mulch film. Therefore, these impacts were only qualitatively assessed.

# Agricultural mulch film

## Thin biodegradable mulch film and thick recyclable PE film as complementary solutions

Chart:  
Global Warming Potential - Consideration of Different PE Mulch Film Thicknesses and Recycling Rates



<b>Collection rate</b>	<b>0%</b>	<b>32%</b>	<b>75%</b>	<b>90%</b>
<b>Recycling rate</b>	<b>0%</b>	<b>90%</b>	<b>90%</b>	<b>90%</b>

➔ Recommended thickness to enable PE mulch film collection and recycling is min. 25 µm

## Overview part 2

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    - Organic waste management
    - Packaging
  
  - Durable and biobased polymers
-

# Organic waste management

## Biodegradable Polymers – Market and applications

### Bio-bin inlayer for organic waste materials

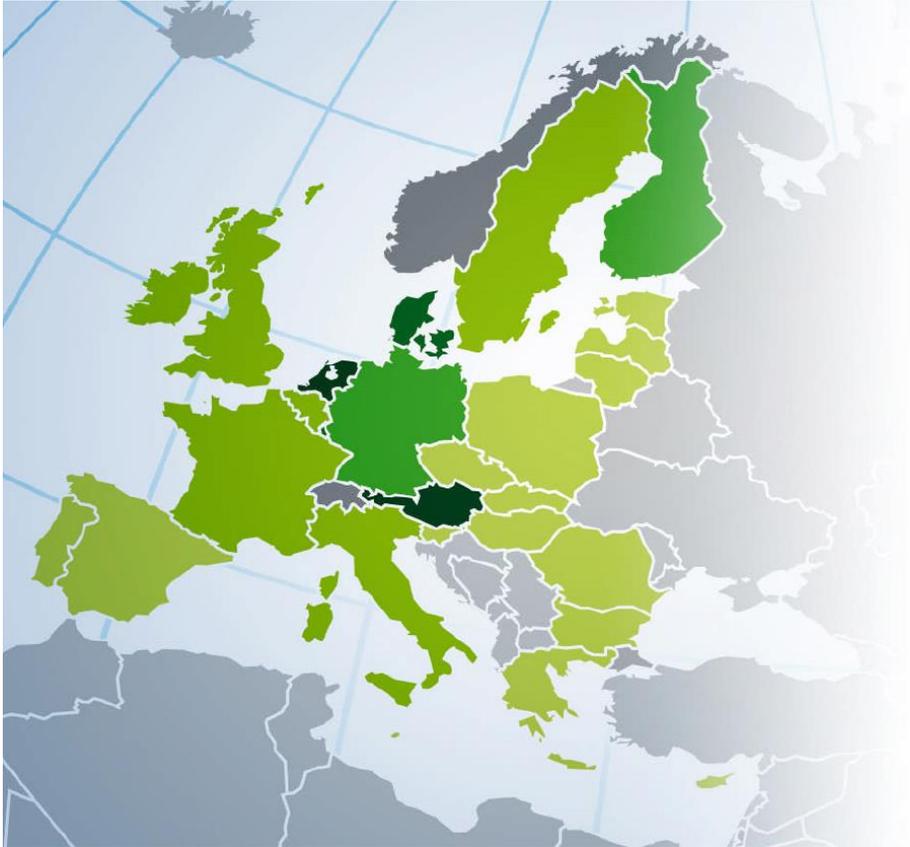


### Fruit & Vegetables Bags



# Organic waste management

## Biological treatment of organic wastes (approx. 40% of total waste): European legislative framework



Share of organic waste collected separately

- > 80%
- 60 - 80%
- 40 - 60%
- 20 - 40%
- 0 - 20%

Source: European Composting Network, p. 127

### Status quo:

→ Less than 30% of organic wastes are collected separately in the EU

# Organic waste management

## Separate collection of food waste makes sense



Source: ROUGH calculations by BASF not third party verified System boundaries: A person uses a bag to collect 1 kg of organic kitchen waste. If PE bag is used, both waste and the bag are disposed off in landfill or incineration plant; if ecovio bag is used, organic waste is composted together with the bag. Assumptions: Incineration of organic kitchen waste is assumed to be without energy recovery (heating value is 3,6 MJ/kg, accepted from the Critical Review Panel on the EEA study of “2 in 1” bag). Energy recovery by incineration of the PE bag is included but of no relevance. In the composting scenario, it is assumed that fertilizers are substituted. Results range: 10% uncertainty

Source: Jens Hamprecht, BASF



# Organic waste management

## ecovio<sup>®</sup> bags as enabler for organic waste collection and treatment



Degradation through microorganisms in compost



- **Water**
- **CO<sub>2</sub>** rebound in the form of ecovio<sup>®</sup>
- **biomass**



Composting **not** possible



- **Disposal in landfill:** not permitted in the European Union 
- **Incineration:** not reasonable due to the high fraction of water in the biowaste 

 ecovio<sup>®</sup>
 ecoflex<sup>®</sup>
 polyethylene
  microorganisms

# Organic waste management

## Pilot trials in cities (e.g. Berlin):

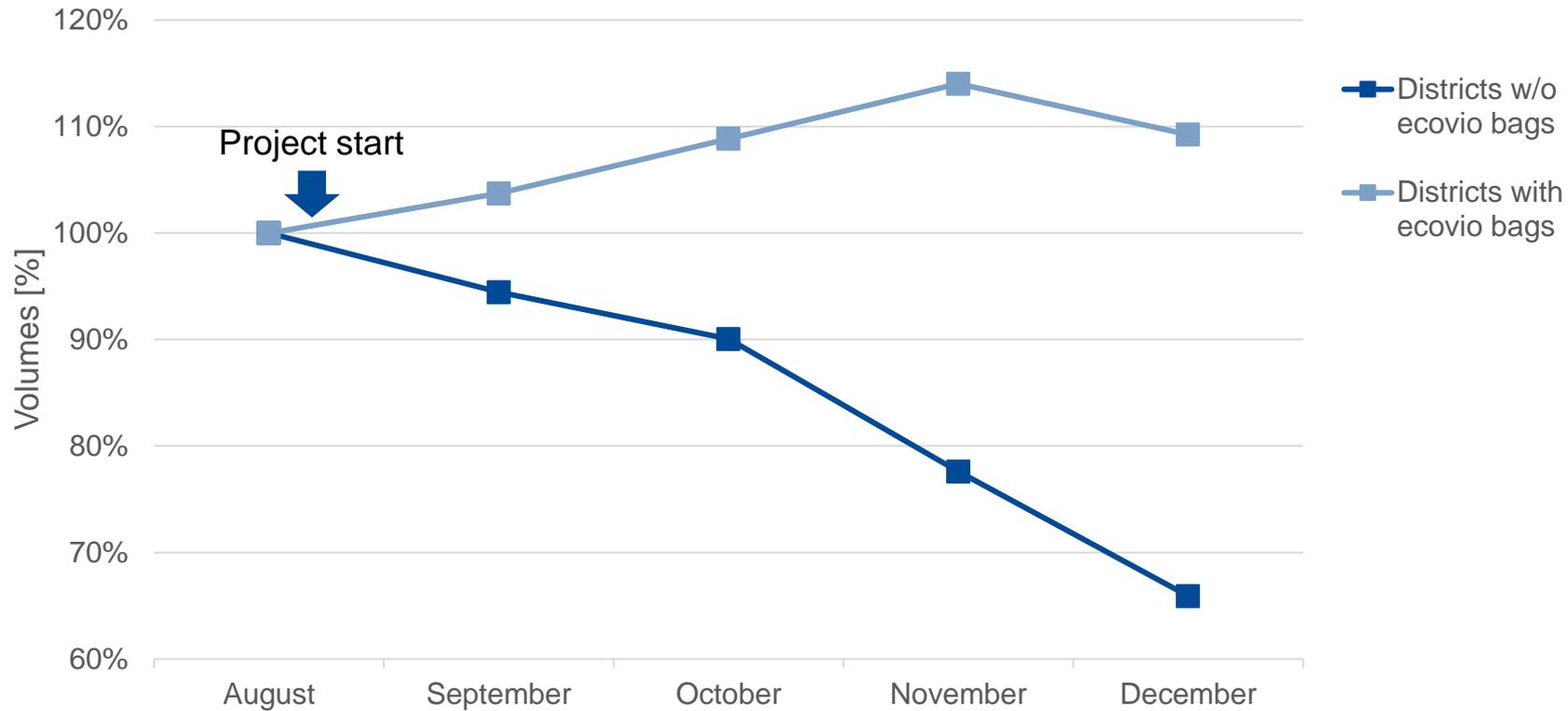
### Consumer feedback for use of ecovio<sup>®</sup> bags in organic waste collection?



→ With ecovio<sup>®</sup> organic waste bags the separate collection of organic waste is cleaner, safer and easier

# Organic waste management ecovio<sup>®</sup> bags lead to more organic waste in the biobin

## Change in organic waste volumes



→ ecovio<sup>®</sup> bags help increase the volumes in the organic waste bin

# Organic waste management

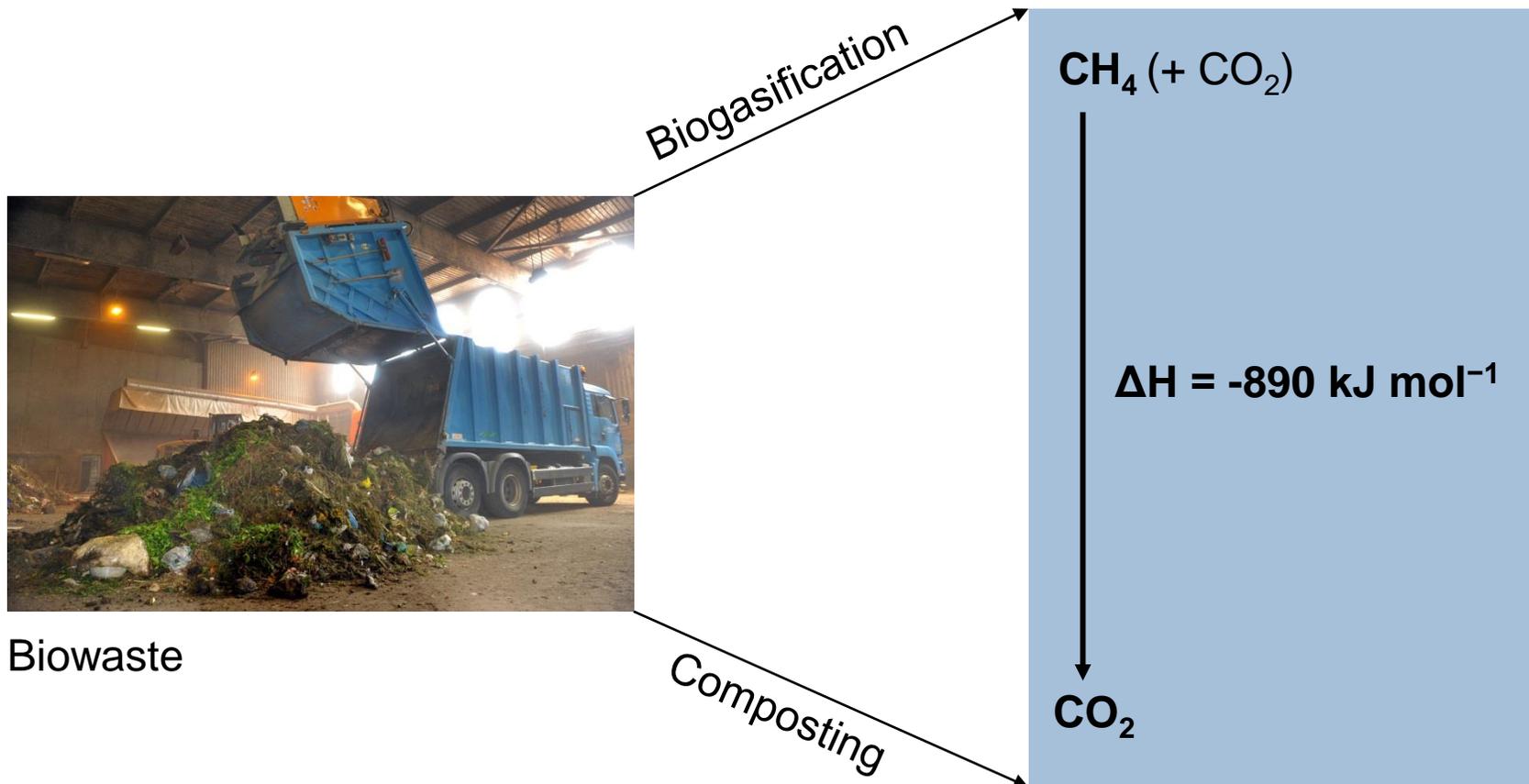
## Do ecovio® bags compost fast enough?



→ ecovio® bags fully compost in the different compost plants

# Organic waste management

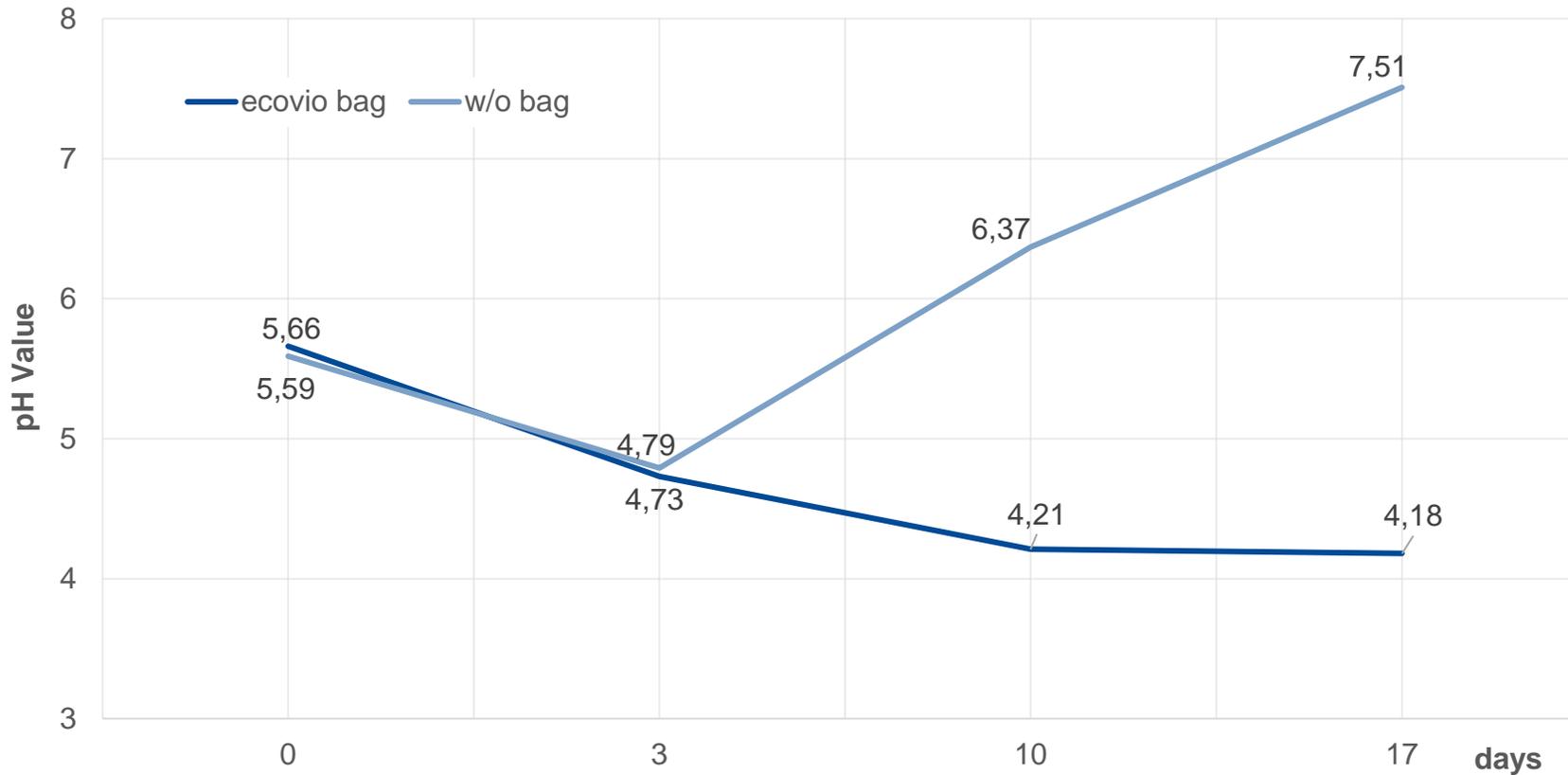
## Energy recovery from organic waste by anaerobic digestion



→ Anaerobic digestion converts organic waste into combustible biogas

## Organic waste management

# Reduced pH value in ecovio<sup>®</sup> bags provides a “silage” conservation effect



➔ Low pH value decreases the microbiological activity of organic waste, therefore save the energy of organic waste for fermentation.

# Organic waste management offers economic and environmental advantages



### Climate protection

- Reduced carbon footprint – up to 25 million t/a CO<sub>2</sub> reduction in EU

### Renewable energy source

- Approx. 80 million t/a municipal biowaste in EU → 8 billion Nm<sup>3</sup> biogas potential (electrical energy for 4-6 million 2-person households)

### Improved nutrition of soil

- Compost provides phosphates (no phosphate reserves in EU)

### Soil protection

- Compost is used to prevent soil erosion

## Overview part 2

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### ■ Biodegradable and biobased polymers

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### ■ Applications of biodegradable and biobased polymers

- Market, legislation, capacities & application overview and public perception
- Agricultural mulch film
- Organic waste management
- Packaging

### ■ Durable and biobased polymers

---

## Packaging – paper coating

# Combination of paper and biodegradable and biobased polymers



- Paper has been the major packaging material 50 years ago
- Due to missing performance characteristics and barrier properties (e.g. fat resistance) paper has been largely replaced by polymers (e.g. PE)
- Paper has an excellent image as packaging material (renewable and biodegradable)
- Using biodegradable/biobased polymers, the missing performance and barrier properties of paper can be compensated

Combination of paper with biodegradable and biobased polymers is leading to a sustainable packaging solution

## Packaging – paper coating ecovio paper coating



- Grade for biodegradable coating with a renewable content of 75%
- Typical applications: hot/cold cups, wrap-pings, buckets, freezer boxes
- Barrier to fat, liquids and aromas
- Scratch resistant
- Food contact approval in EU and North America
- Compostability: EN13423 and ASTM6400
- Enabler for improved paper recycling

Combination of paper with biodegradable and biobased polymers is leading to a sustainable packaging solution

Packaging – coffee capsules  
Coffee: past and present

1908



2006



# Packaging – coffee capsules ecovio<sup>®</sup>, biodegradable coffee capsules

Coffee consumption in Germany: citizen/day



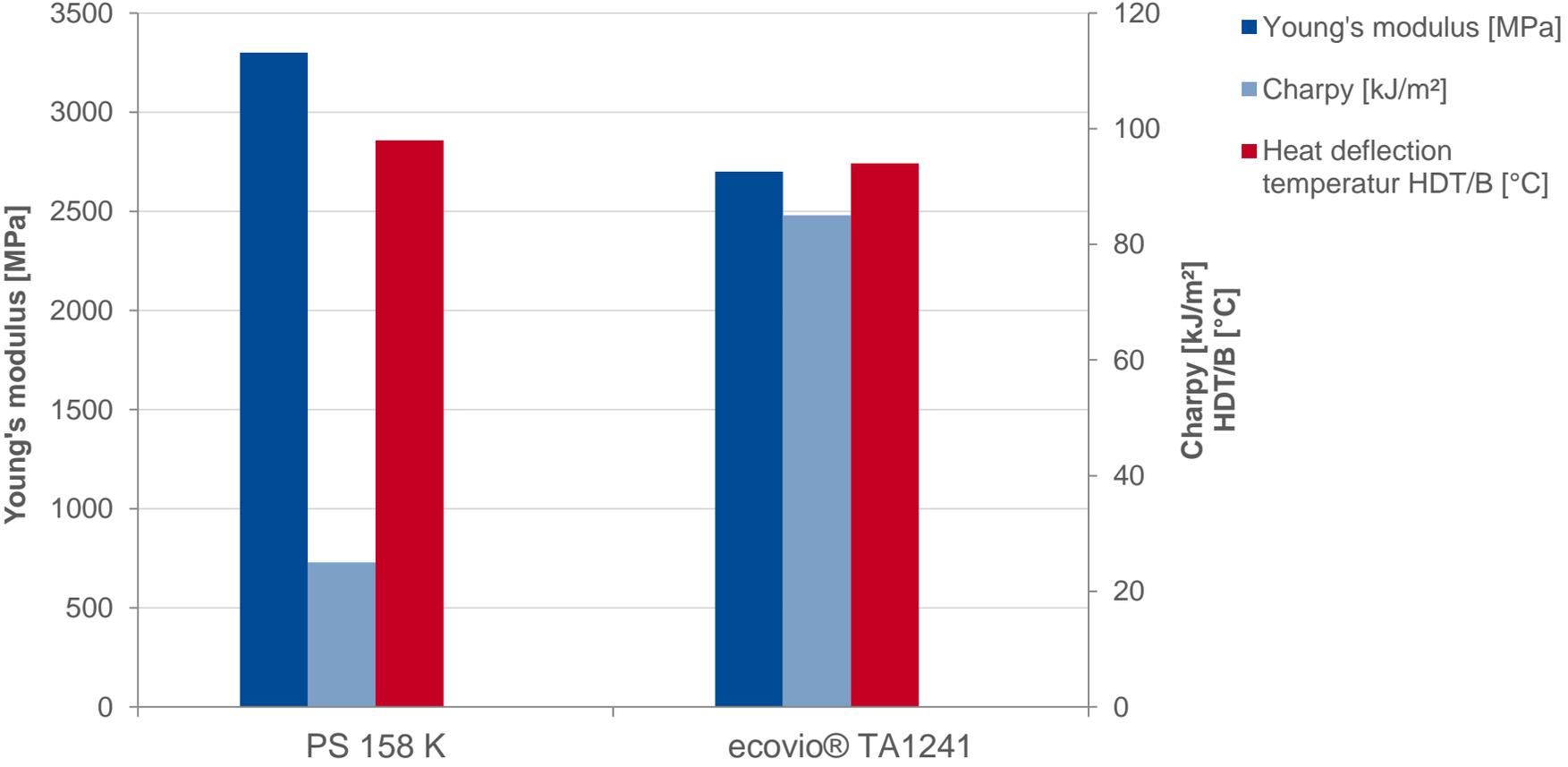
→ To use coffee grounds as composting material, degradable capsules are required

Packaging – coffee capsules  
ecovio® as complete packaging solution



Packaging – coffee capsules

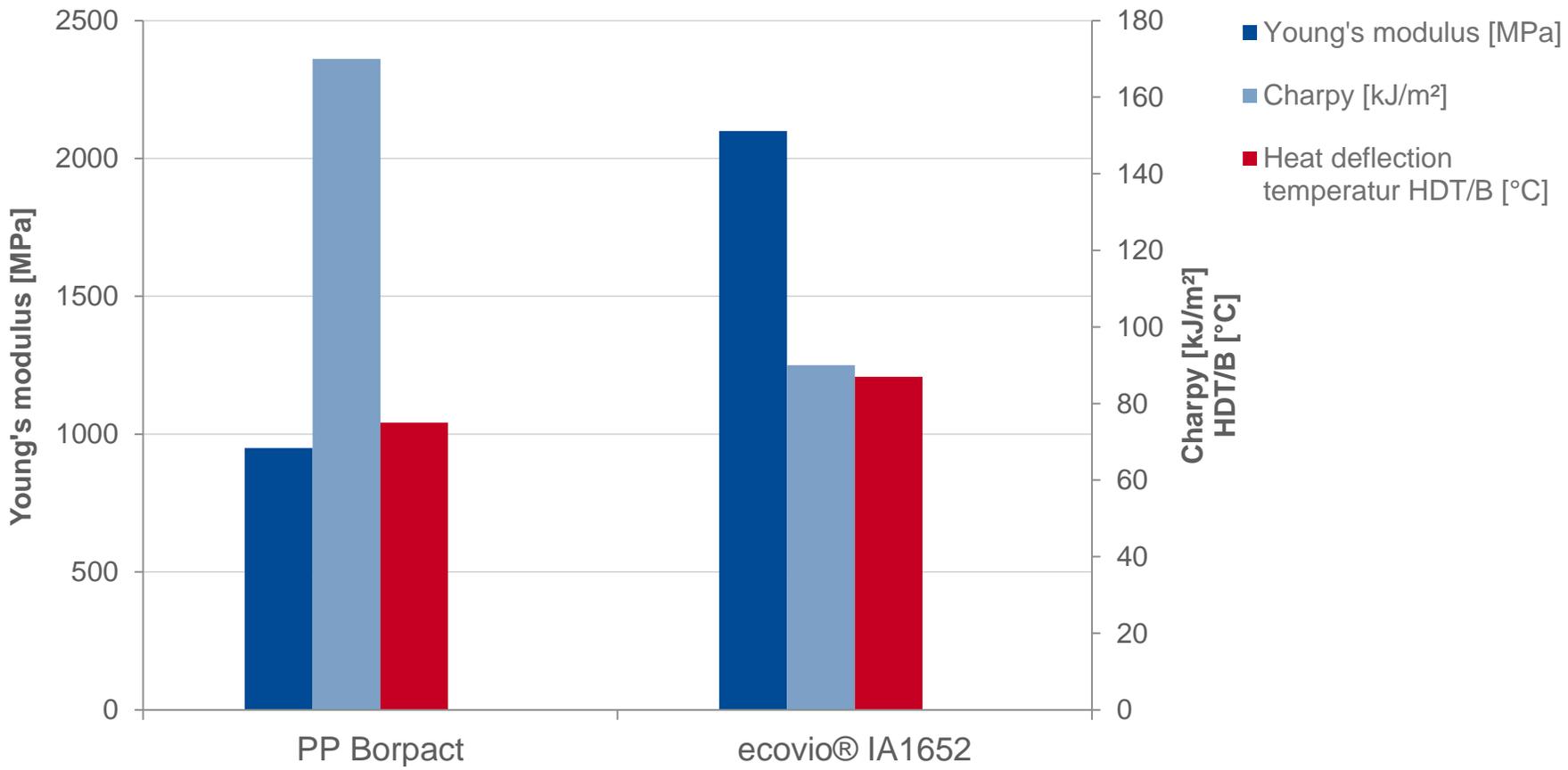
# Comparison of mechanical properties of Polystyrol (PS) and ecovio®



➔ Heat stability combined with flexibility

Packaging – coffee capsules

# Comparison of mechanical properties of Polypropylene (PP) and ecovio®

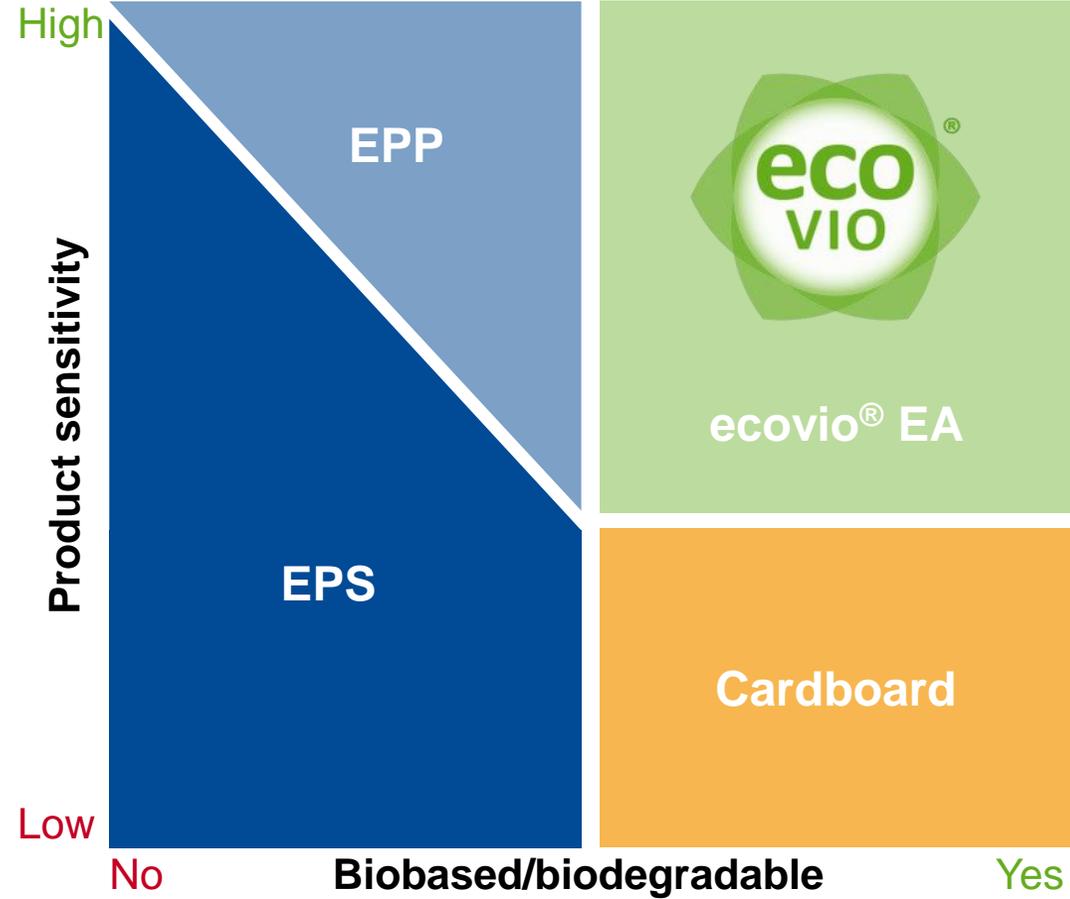


→ ecovio® comparable to stiff PP

# Packaging – particle foam

## Biodegradable and biobased alternative to EPS

Target area for ecovio® EA



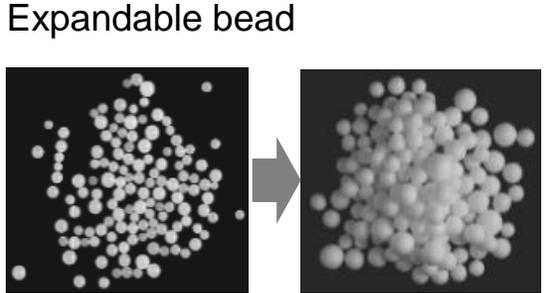
# Packaging – particle foam Properties

## Product quality 1/2

	EPS	ecovio <sup>®</sup> EA foam*
Density (g/L)	25	25
Expandable bead density (g/L)	~ 600	~ 680
Cushioning factor	2.5	2.7
Compressive strength @ 10% (kPa)	175	90
Flexural work to break (J)	2.5	2.7
Flexural strength (kPa)	420	220

## ecovio<sup>®</sup> vs. EPS

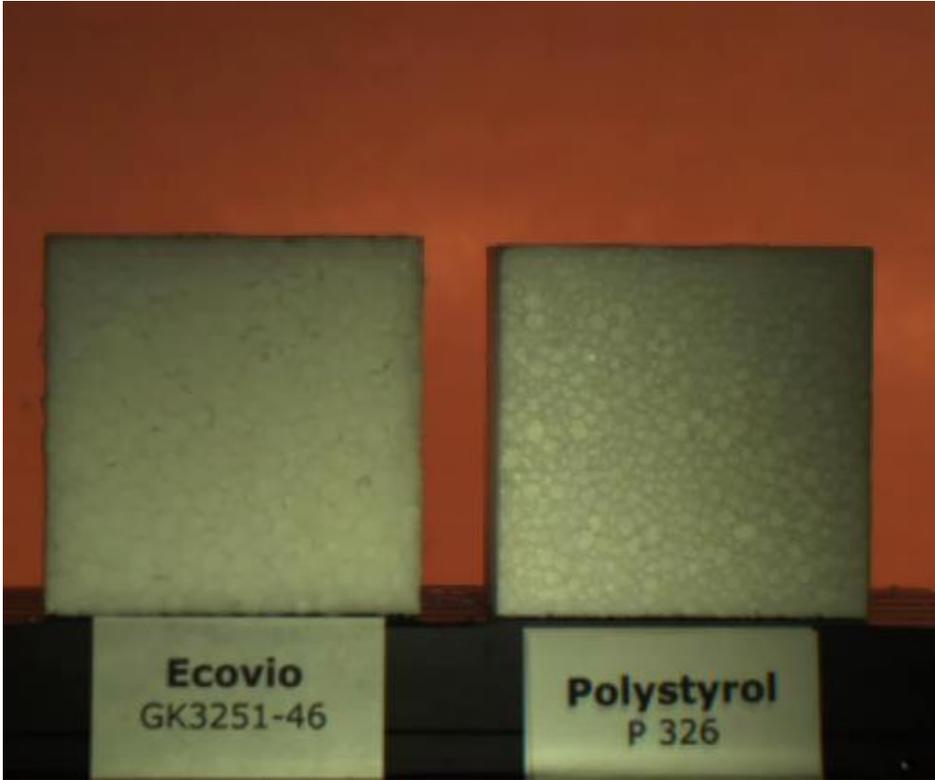
- Comparable density
- Multi-shock resistance foam
- Ready to use expandable beads
- Drop-in solution combined with energy savings



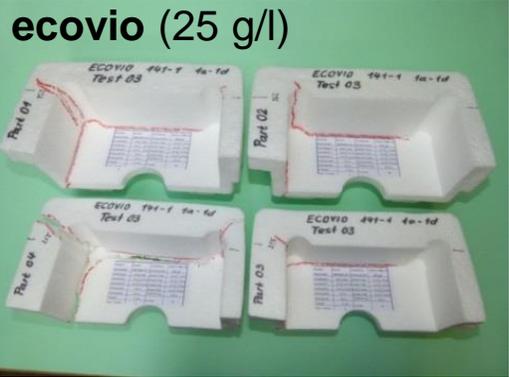
# Packaging – particle foam

## Key properties for packaging application

### Elastic property (ecovio<sup>®</sup> vs. EPS) @30 g/l



### Multi-drop test (10 times impact)

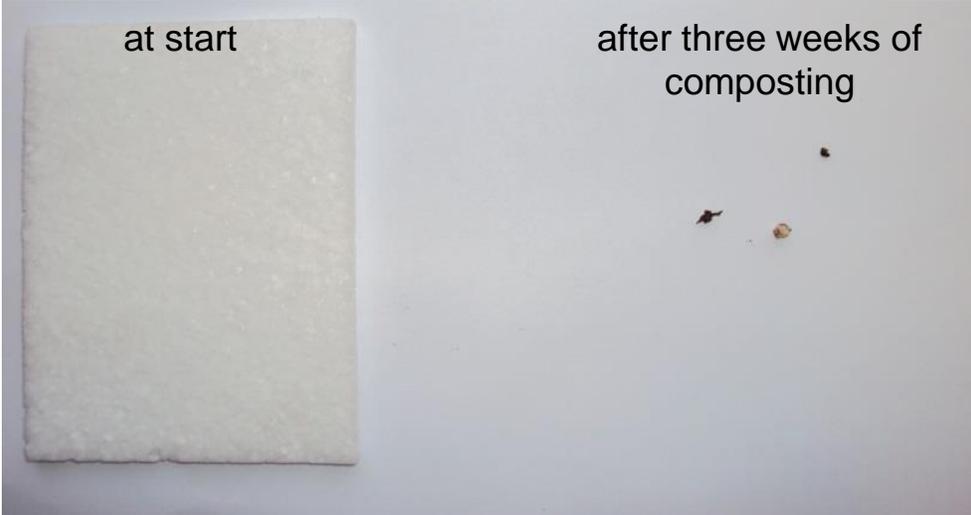


# Packaging – particle foam

## Biodegradation of ecovio EA foam

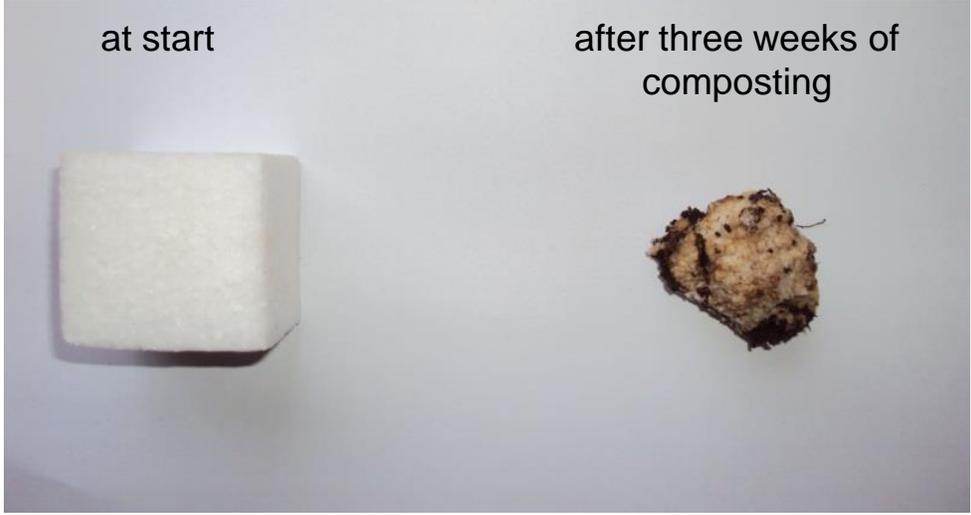
### Industrial compostable ecovio® EA foam

**ecovio® EA foam (11.7 x 8.8 cm<sup>2</sup> pieces)**



**Sample 1**  
**Thickness 0.6 cm (cup)**

**ecovio® EA foam (5 x 5 x 5 cm<sup>3</sup> pieces)**



**Sample 2**  
**Thickness 5 cm (box)**

Biodegradable  
(DIN EN 13432)



Fast disintegration of ecovio foam (DIN EN 13432) in 4 weeks

# Biodegradable and biobased polymers and applications

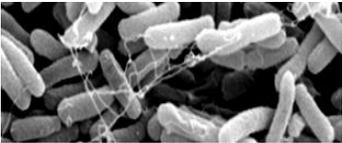
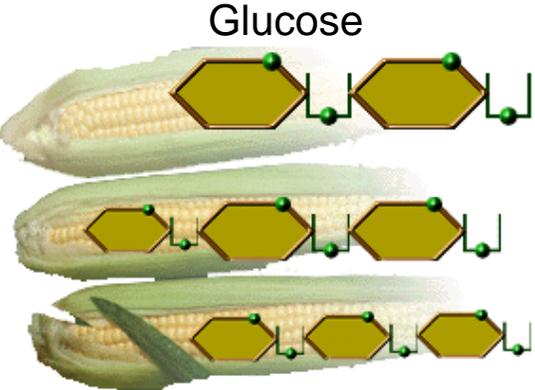
## Overview part 2

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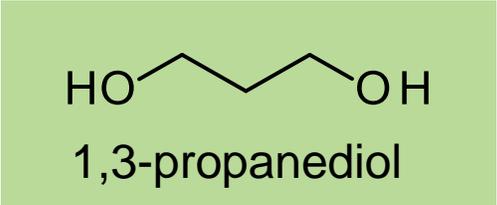
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- Durable and biobased polymers

# Durable and biobased polymers

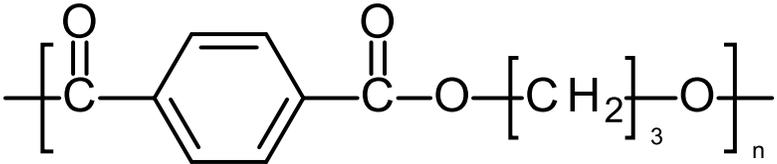
## Polytrimethylene terephthalate (PTT) based on 1,3-propanediol



fermentation



+ terephthalic acid



PTT Sorona<sup>®</sup>, DuPont

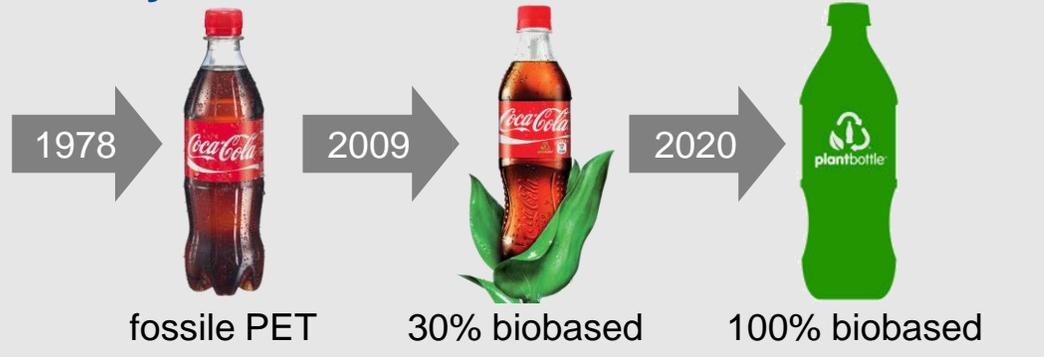
### Properties:

- semi-crystalline, thermoplastic
- 27% biobased (based on C)
- high resilience for fibers

# Durable and biobased polymers

## Coca Cola`s target is to develop a biobased, recyclable bottle

### History & Vision



### Claims

**plantbottle™**  
 up to 30% plant-based  
 100% recyclable bottle  
 redesigned plastic,  
 recyclable as ever.

### Companies for monomers and polymers

avantium      VIRENT  
 gevo™

O=C(O)c1cc(OC(=O)O)oc1      OC(=O)c1ccc(cc1)C(=O)O

### Partnering

Plant PET  
 Technology Collaborative

Nestle      bfa Bioplastic Feedstock Alliance  
 Unilever      DANONE      WWF®

Ford      Heinz      NIKE  
 P&G      The Coca-Cola Company

### Motivation & Benefits

- Numerous awards (e.g. by Walmart)
- Increased sustainability (CO<sub>2</sub> savings of 140 kt until 2013)
- Increased brand image & sales

### Cost

- Currently 50% premium for bio-EG
- Coca-Cola expects future cost parity



We create chemistry