Cicle de conferències

Bioenergia i Biomaterials

Abril – juny 2026

Obtenció de bioplàstics

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Interfibio

Catàlisi Heterogènia

Organitza:

Societat Catalana de Tecnologia · I · E · C ·

Enginyers Industrials de Catalunya

amb la col·laboració de:

Generalitat de Catalunya

CBC Clúster Bioenergia Catalunya

Enginyers agrònoms de Catalunya
L'enginyeria que alimenta el món

amb el suport de:

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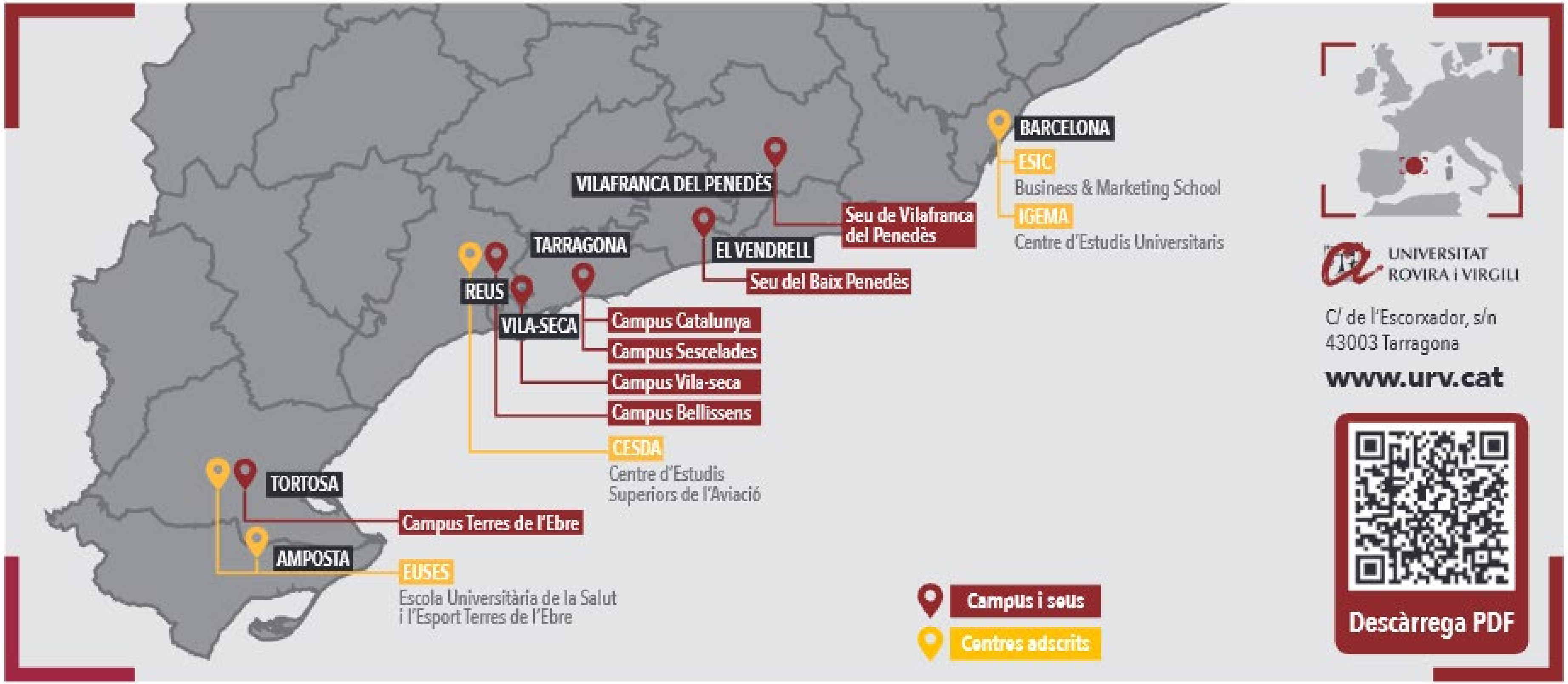
LA URV A CATALUNYA

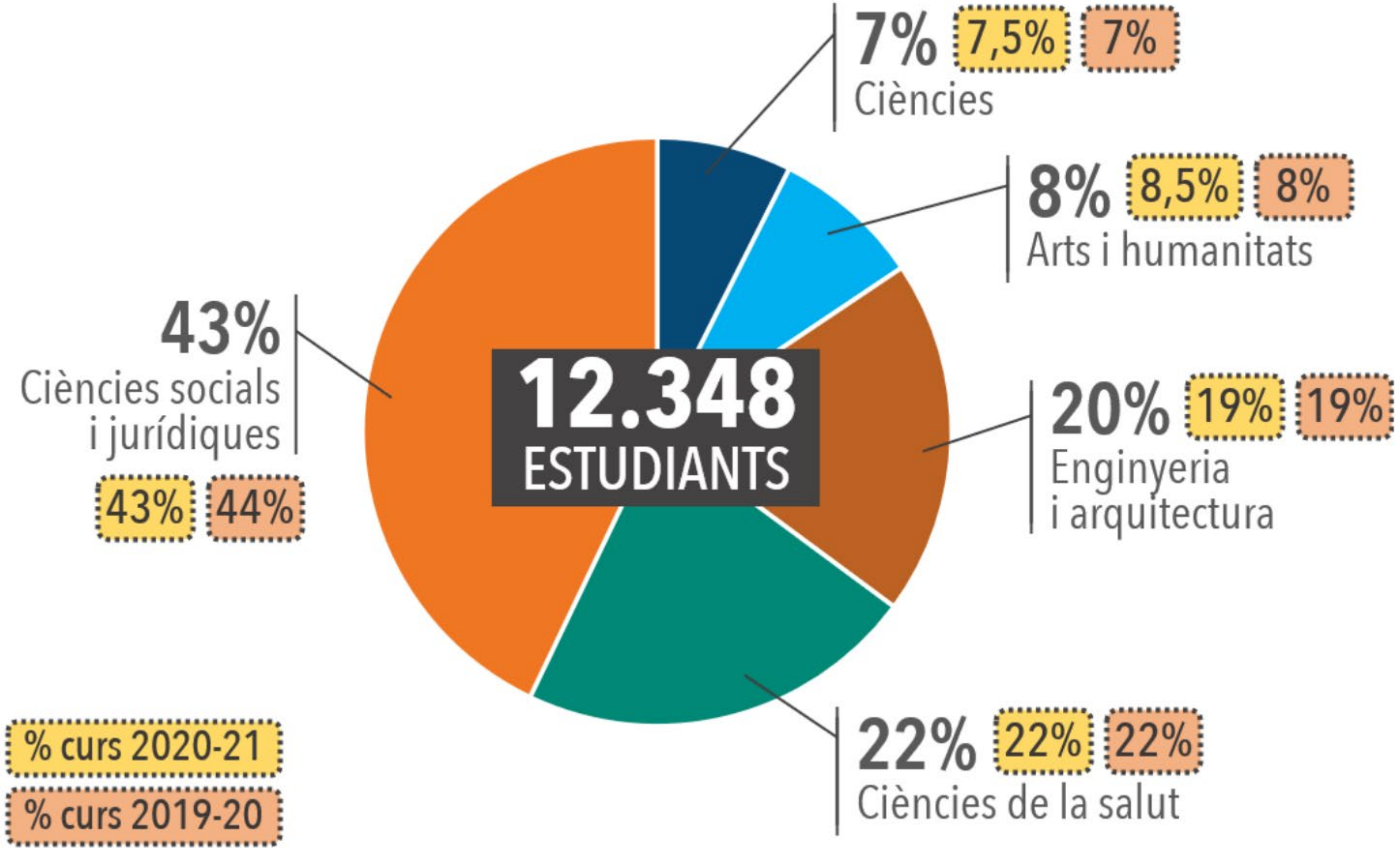


58 GRAUS

61 MÀSTERS

26 DOCTORATS

URV: la Universitat pública de Tarragona



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Obtaining bioplastics

Contents

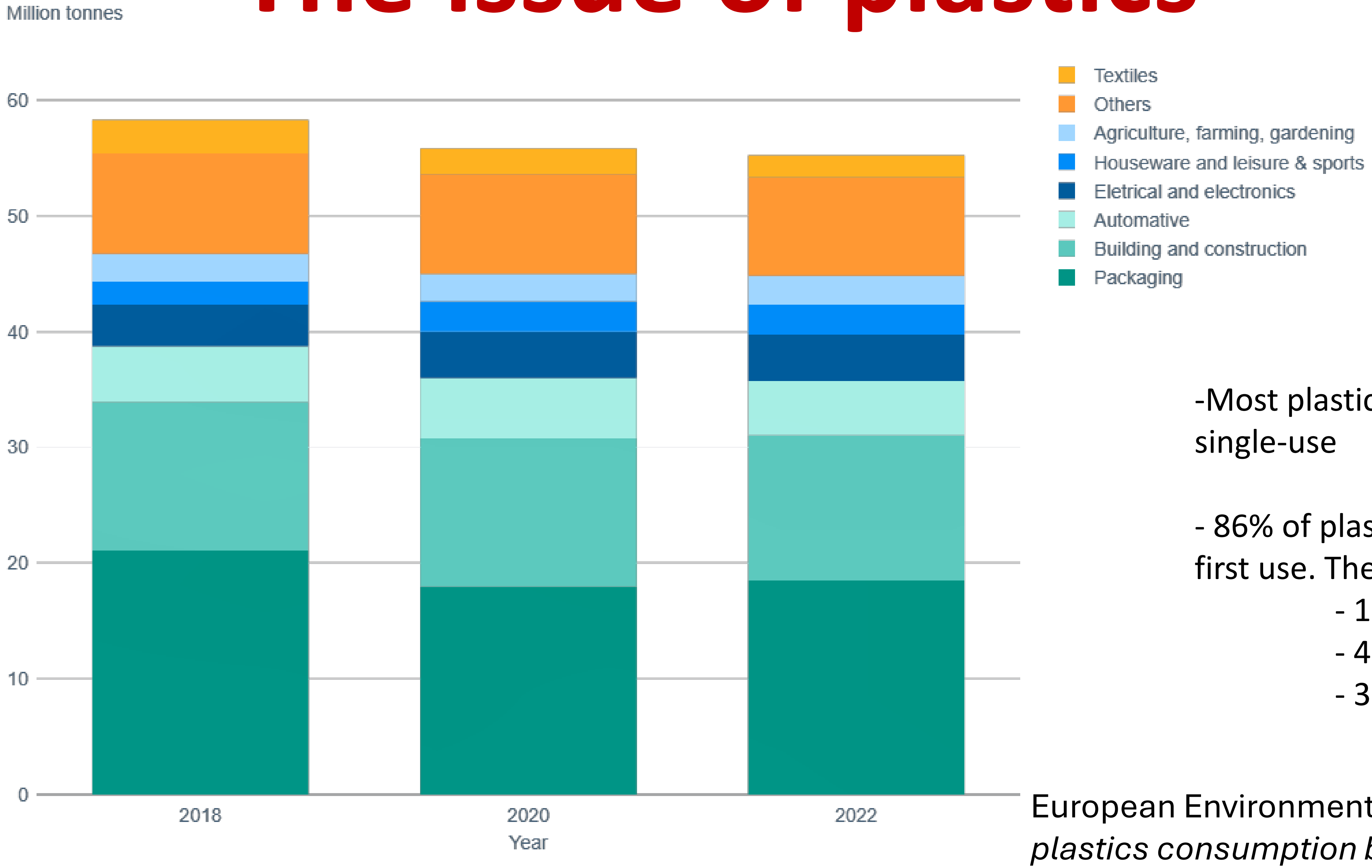
- Current challenges
  - New materials for replacing petrochemical plastics
  - Substitution of fossil fuels
- Lignocellulosic biomass
- Conversion of biomass to high added value products
  - Physical-chemical treatment
  - Biological treatment

Current challenges

- **New materials for replacing petrochemical plastics**
- **Substitution of fossil fuels**

New materials for replacing petrochemical plastics

The issue of plastics



-Most plastics are used for packaging, single-use

- 86% of plastics are eliminated after the first use. The fate is :
  - 16% is burned
  - 47% landfills
  - 37% oceans

European Environment Agency. (2023). *Total plastics consumption by end-users in the EU27+3*.

https://www.eea.europa.eu/en/circularity/sectoral-modules/plastics/total-plastics-consumption-by-end-users-in-the-eu-3

Plastics in the oceans

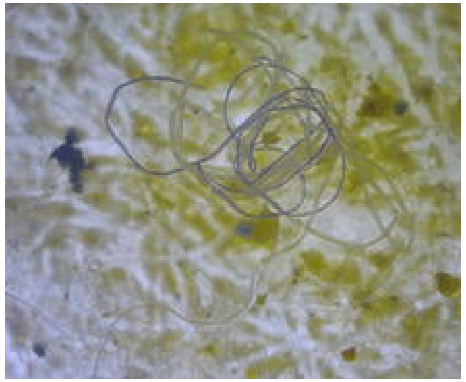
8 million tons per year (800x weight of the Eiffel Tower)
8 trillions of dollars (damage to the oceans)
Ecosystems, 400 years to degrade

Plastic Island (Pacific Ocean, 3,4 x 10^6 km^2)
Photodegradable plastics → Microplastics → Food chain

Distribution
70% bottom 15% water column 15% surface

http://www.onegreenplanet.org/animalsandnature/marine-animals-are-dying-because-of-our-plastic-trash/
https://www.msn.com/en-us/news/world/a-sperm-whale-that-washed-up-on-a-beach-in-spain-had-64-pounds-of-plastic-and-waste-in-its-stomach/ar-AAvLFJ6?ocid=spartanntp&fullscreen=true#image=2

Microplastics



Microplastic fibers identified
in the marine environment

Size < 5 mm diameter
(National Oceanic and Atmospheric Administration (NOAA))
Sources: cosmetics, clothing, fishing gear, everyday plàstic waste, Industrial processes
Two types of microplastics
- **primary**: manufactured to be used in products
- **secondary**: formed from the breakdown of larger plastic waste

They remain in marine ecosystems
Jellyfish → food chain

Garbage islands

2 in the Pacific Ocean (North: 1988, South: 2011)
Atlantic Ocean (North: 2009)

Garbage Island

- North Pacific
- Discovered by ocean captain and researcher Charles Moore
- 3,4 million km^2 (7x Spain)
- Origin of the waste
  - 80% from land-based sources
  - 20% from ocean ships
- Photodegradable Plastics → microplastics → trophic chain
- 267 species affected worldwide

https://www.youtube.com/watch?v=WkWs2ljF904

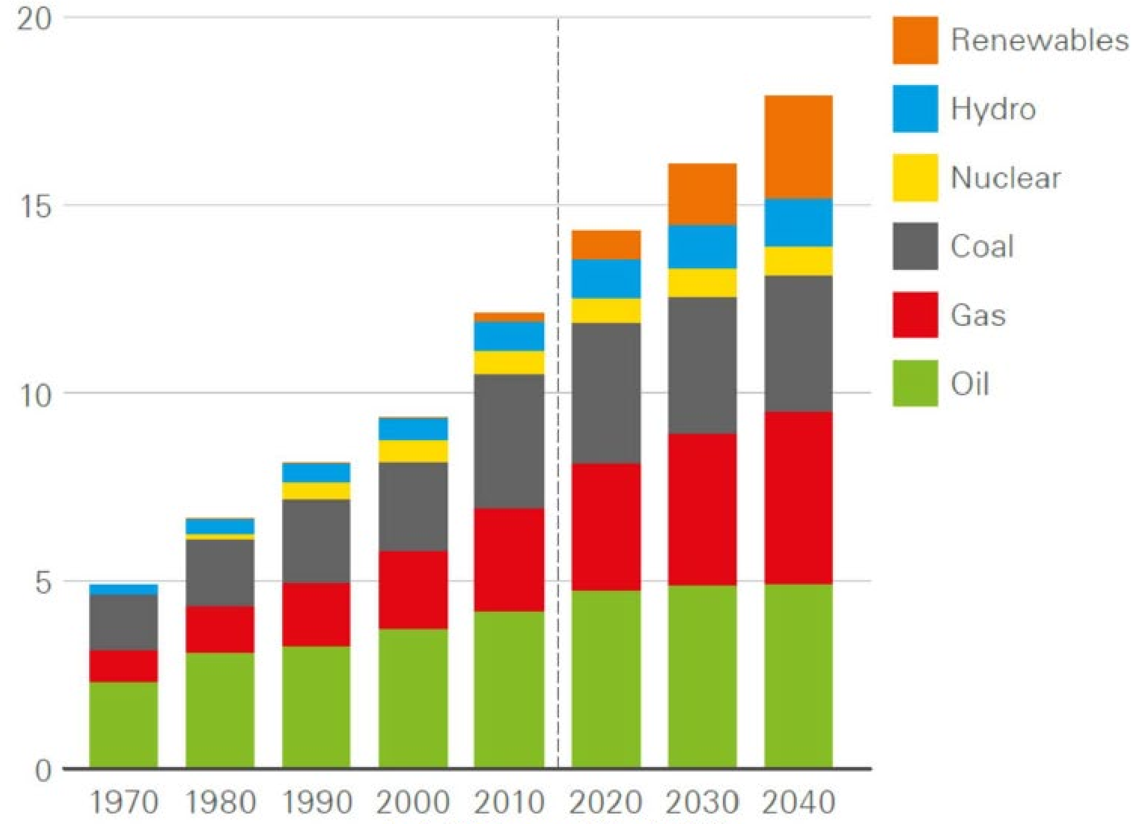
Economic consequences

- Microplastics (< 5 mm): ingestion by marine fauna → food chain
- Ghost fishing: abandoned fishing gear (macroplastics)
- Tourism sector: visual impact
- Costs of cleaning beaches and coastal areas: EU, €630 million annually

Substitution of fossil fuels

Evolution of global energy consumption

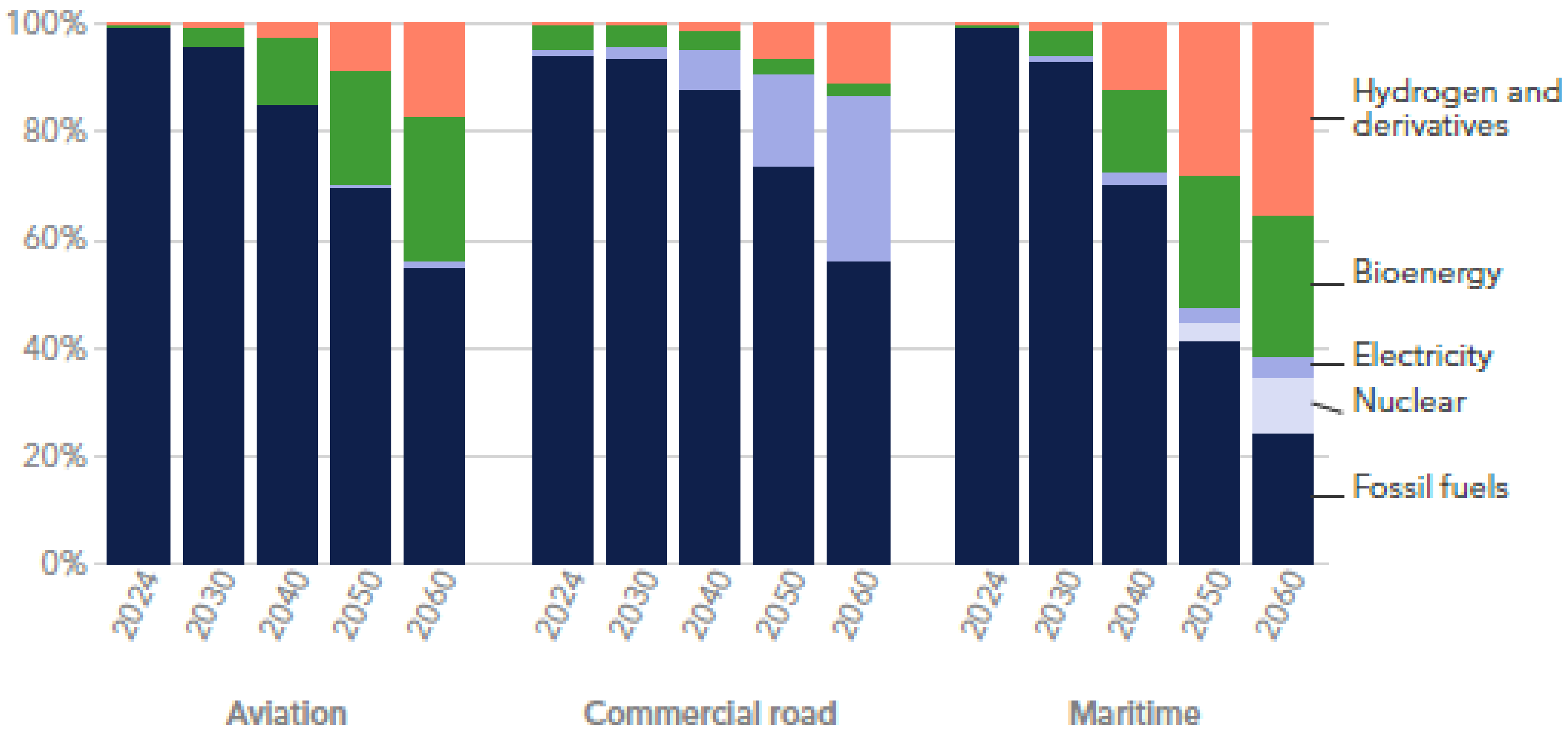
(billions of tep vs. years)



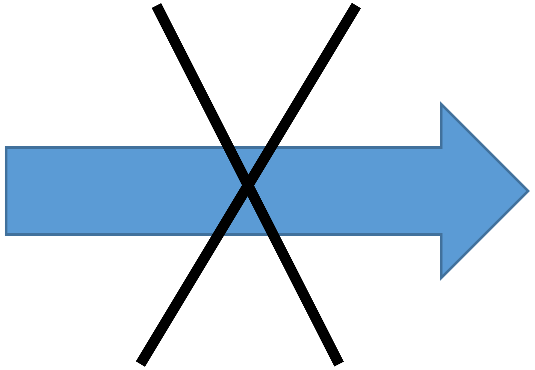
Font: BP Energy Outlook 2019

tep = ton of oil equivalent

Final energy demand by energy carrier, selected transport subsectors



Source: Energy transition Outlook 2025. DNV



PLASTIC
ENERGY

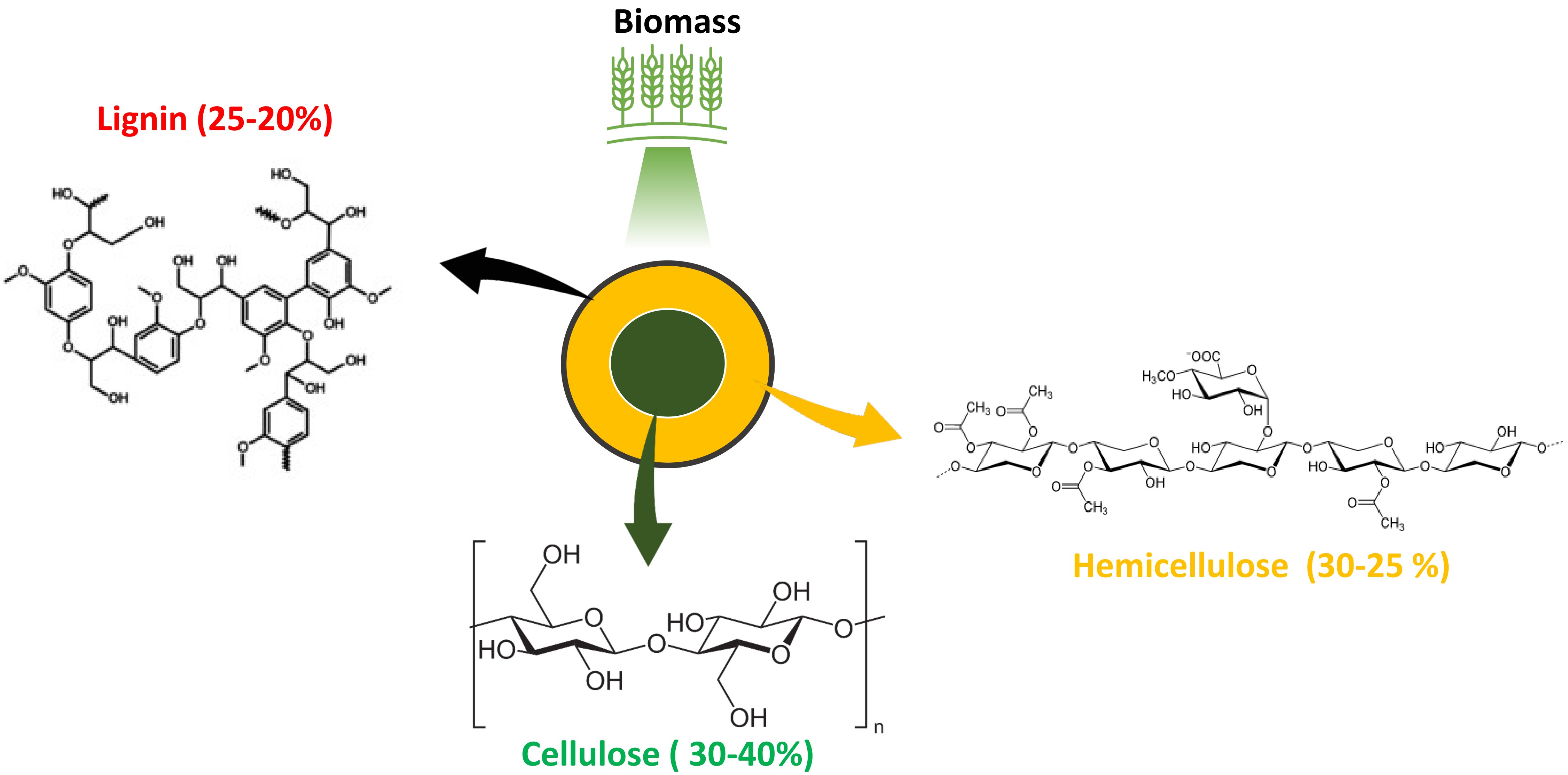
Circular economy

BIOPLASTIC
RENEWABLE
ENERGY

BIOREFINERY: BIOMASS

Lignocellulosic biomass

- ✓Walnut shell
- ✓Rice husk
- ✓Spent coffee grounds
- ✓Pine waste
- ✓Garden waste, wheat and sunflower



Biomass

Lignin (25-20%)

Cellulose (30-40%)

Hemicellulose (30-25 %)

World walnut production and biochemical composition

Country	Walnut production in 2001 (tons)
China	330.000
United States	254.000
Iran	138.000
Türkiye	136.000
Spain	10.000

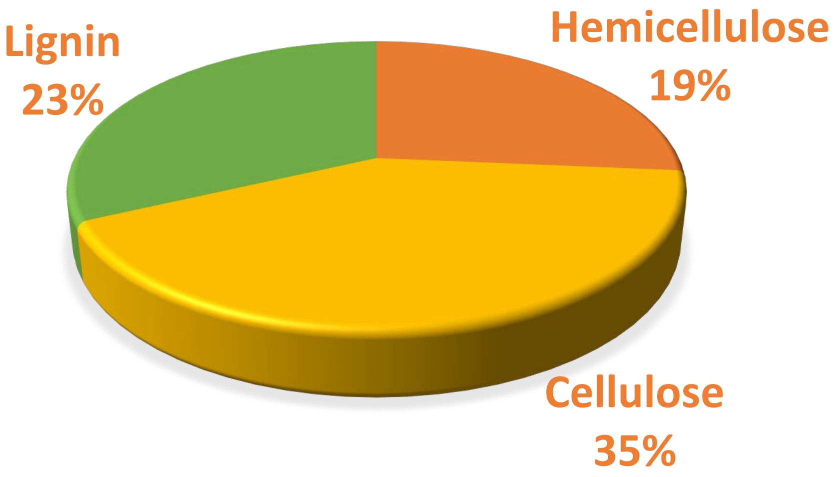
Cellulose	**25.6 wt %**
Hemicellulose	**22.1 wt %**
Lignin	**52.2 wt %**

Source: https://www.infoagro.com/frutas/frutos_secos/nogal.htm (FAO)

Production of rice and biochemical composition

- World production: More than 500 million tons per year (90% Asia)
- Spain: 0,825 million tons per year (position 41)
- Grain of rice: 70-80 % starch, phosphorus, iron , potassium
- Rice husk (15 % silica):

Biochemical composition of rice husk (%)



Spent coffee grounds: world production and composition

Compound	Contents (wt %)
Cellulose	10
Hemicellulose	40
Lignin	30
Extractives	20

World consumption of coffee (2018):
9.5 million tons

1 ton: 650 kg spent coffee grounds

[Incapto – Del residuo al recurso](https://www.youtube.com/watch?v=pT57XV0cPVI)
https://www.youtube.com/watch?v=pT57XV0cPVI

Conversion of biomass to high added value products

- ✓**Lactic acid**
- ✓**PHA’s**
- **Biohydrogen, ethanol**

Physical-chemical treatment

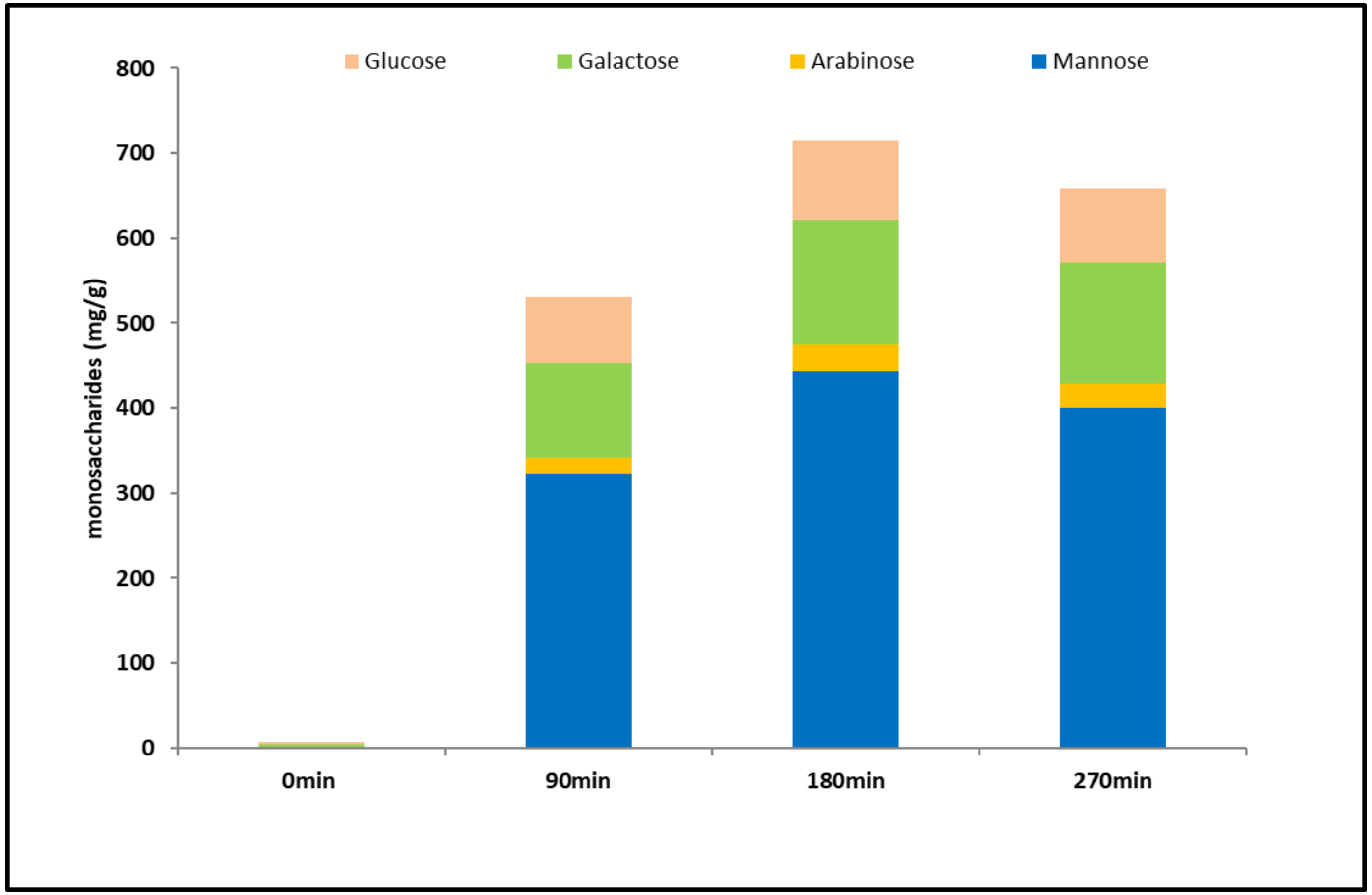
- ✓**Diluted acids**
- ✓**Selective and fast**
- ✓**Environment-friendly**

Mechanocatalysis depolymerization

Selected optimal conditions

- ✓Diluted H_2SO_4, oxalic acid
- ✓180 min
- ✓Environment-friendly

Effect of coffee grounds grinding time on monosaccharide production



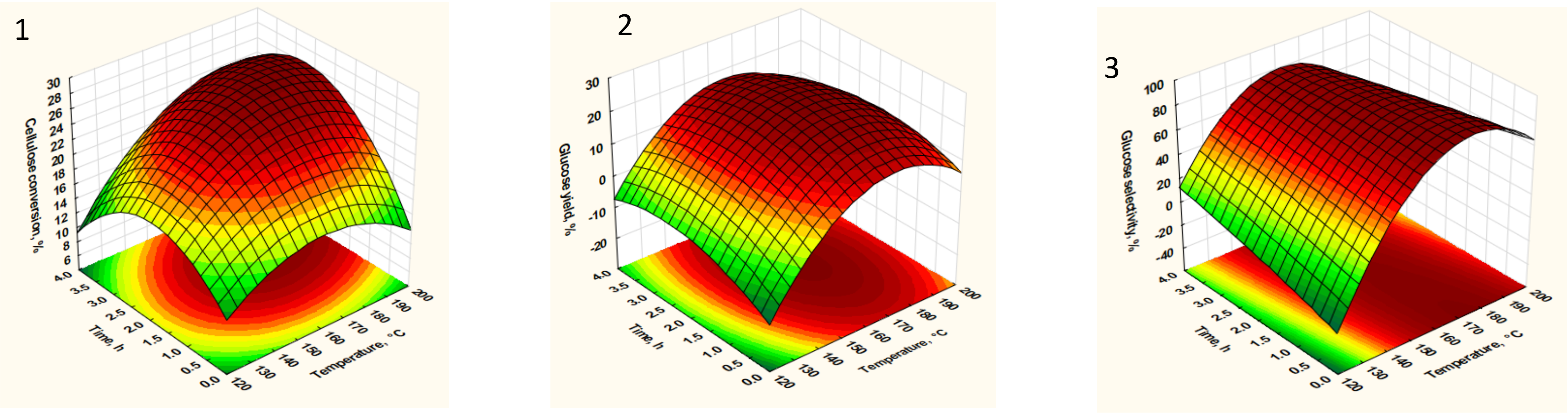
Conditions :
$[H_2SO_4]$= 0,88 mmol/g (1,5M)
Grinding time (0-270 min),
Microwave reactor: 20 min,
150°C

Assisted hydrolysis in a microwave reactor

Selected optimal conditions

- ✓Diluted H_2SO_4 (0,5 M)
- ✓20 min-2 h
- ✓140 – 190 ºC

Results of hydrolysis with pine residue



ANOVA Response surface plots 1) Cellulose conversion 2) Glucose yield 3) Glucose selectivity

Ceaser et al, 2024

Biological treatment

- ✓**Bacteria**
- **Yeast**
- **Enzymes**

Detoxification of spent coffee ground hydrolysate : activated carbon

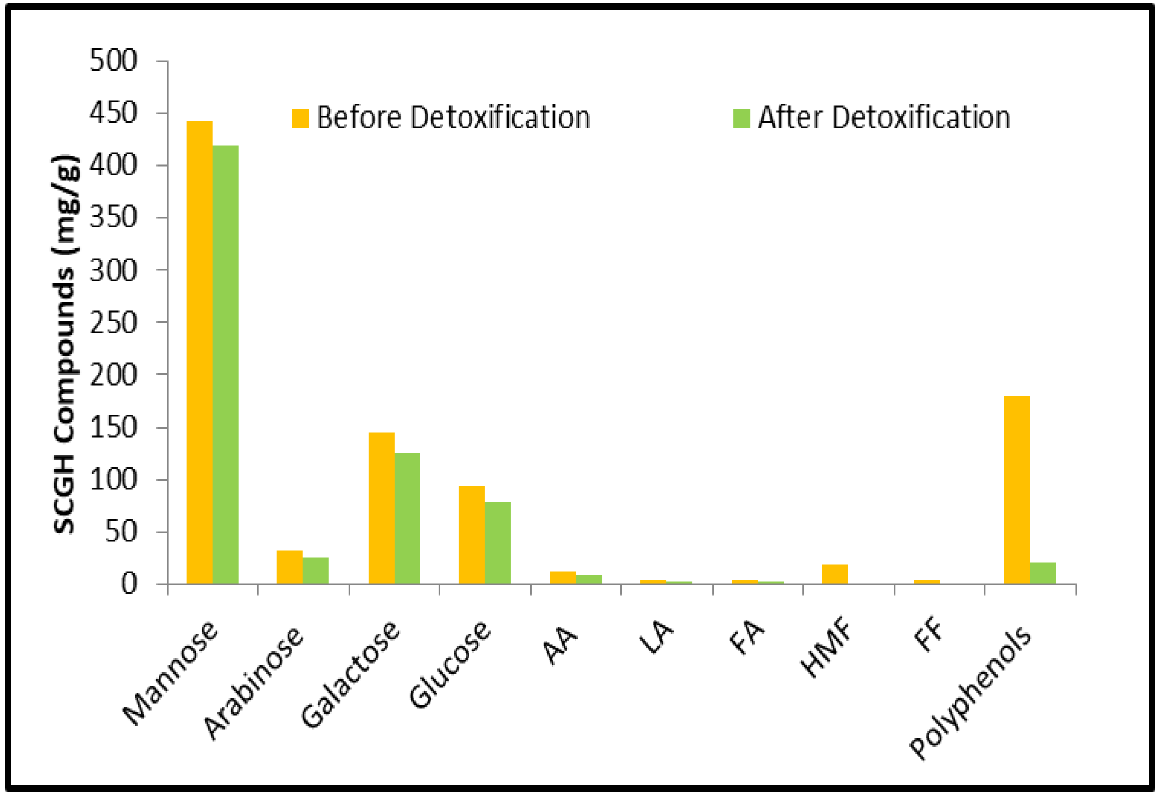
Before

Detoxification

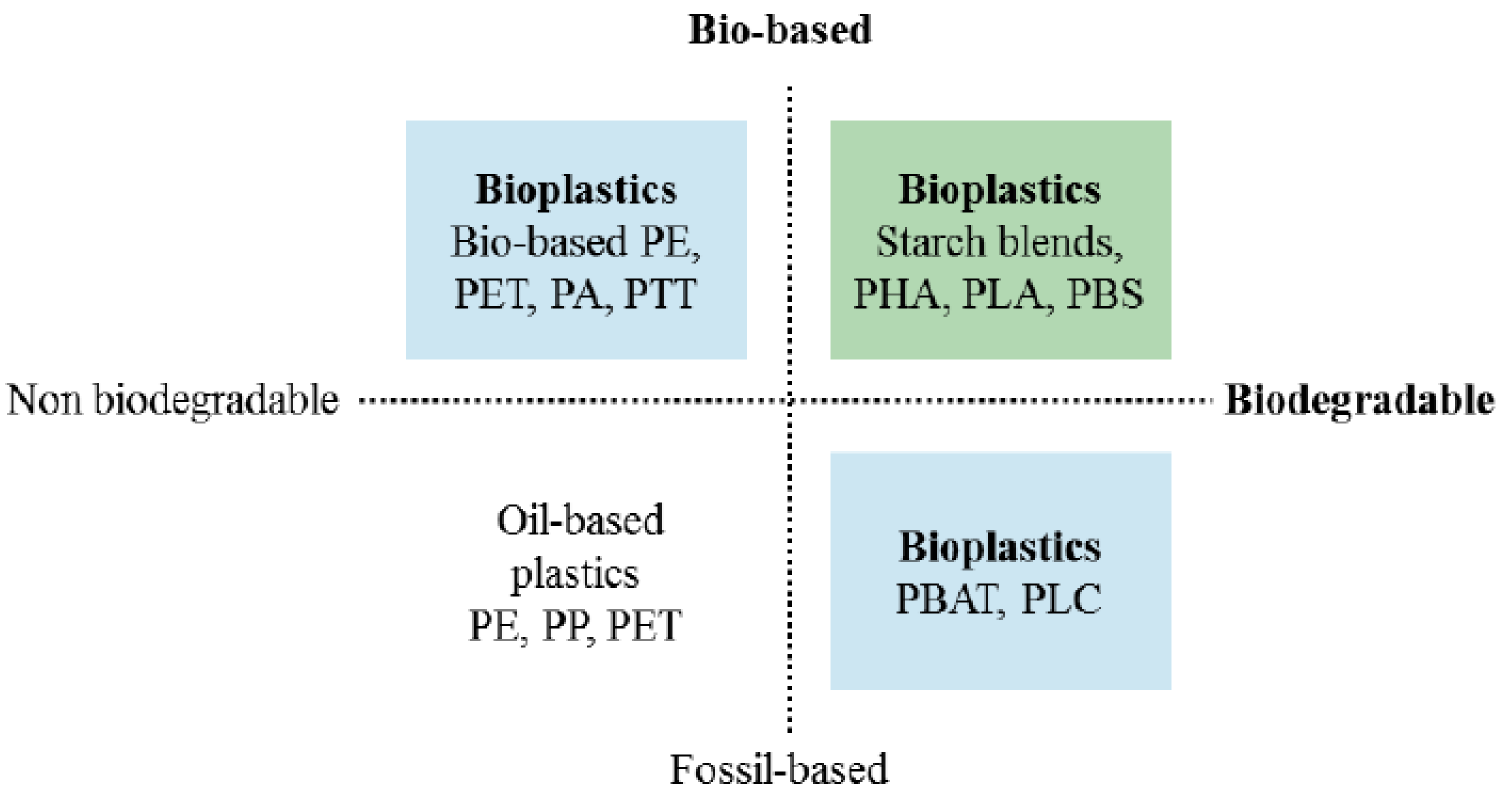
→

3%(w/v) of AC

After



Origin of plastics



Bio-based

Bioplastics
Bio-based PE,
PET, PA, PTT

Bioplastics
Starch blends,
PHA, PLA, PBS

Non biodegradable

Biodegradable

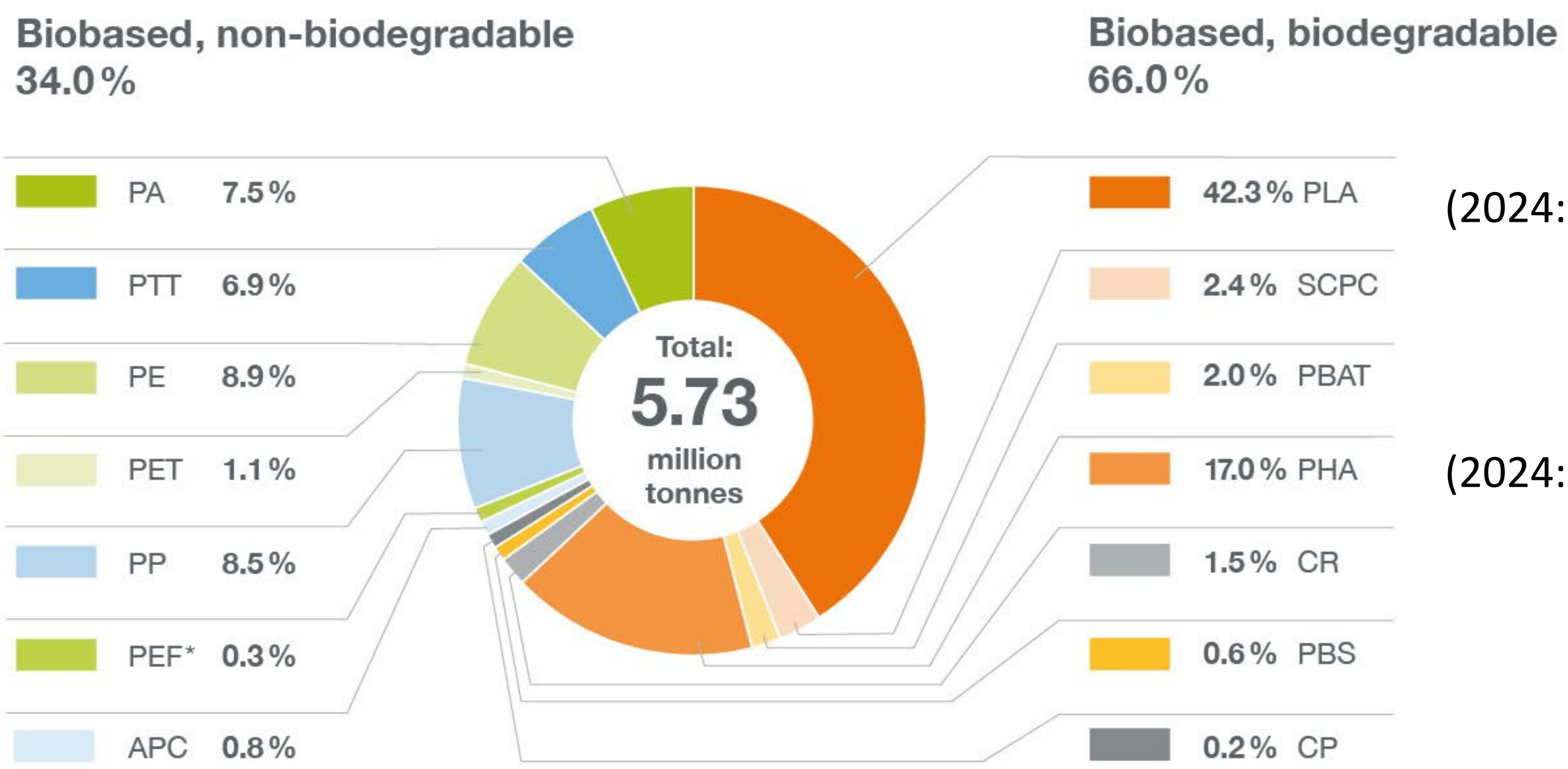
Oil-based
plastics
PE, PP, PET

Bioplastics
PBAT, PLC

Fossil-based

Ferré, A. 2018

Global production capacities of bioplastics 2029



(2024: 37,1 %)

(2024: 4,1 %)

APC	Aliphatic Polycarbonates	PBS	Polybutylene Succinate and Copolymers	PHA	Polyhydroxyalkanoates
CP	Casein Polymers			PLA	Polylactic Acid
CR	Cellulose Regenerates	PE	Polyethylene	PP	Polypropylene
PA	Polyamides	PEF	Polyethylene Furanoate	PTT	Polytrimethylene Terephthalate
PBAT	Poly(Butylene Adipate-co-Terephthalate)	PET	Polyethylene Terephthalate	SCPC	Starch Containing Polymer Compounds

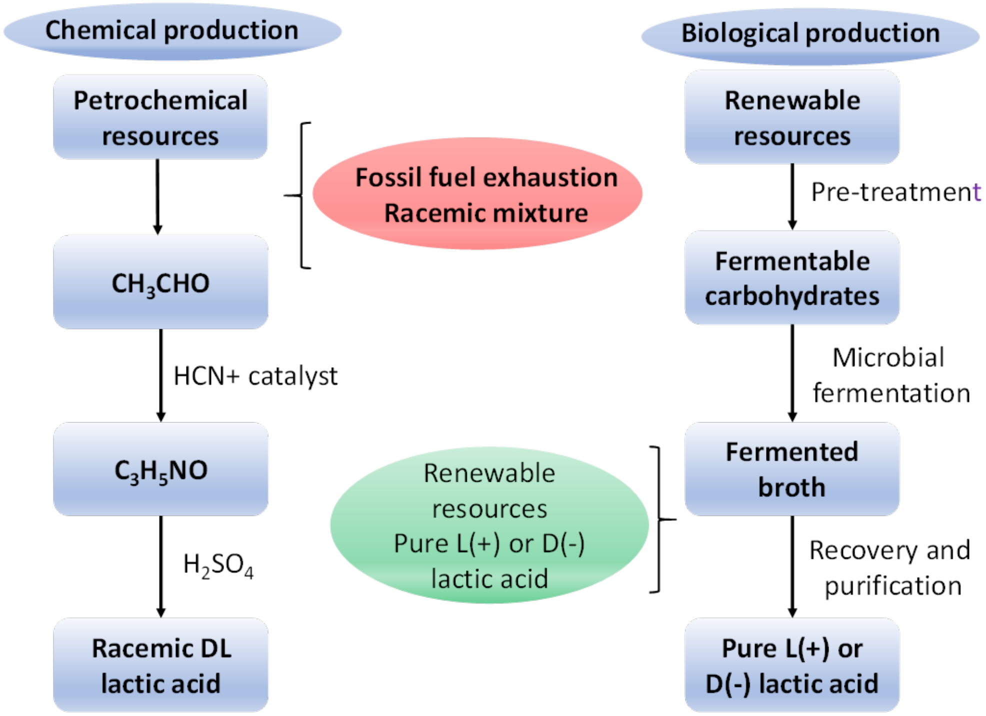
* PEF available at commercial scale as of 2024

Source: European Bioplastics, nova-Institute (2024)

https://www.european-bioplastics.org/market/

Bacterial production of lactic acid

(*Bacillus coagulans*)



Chemical production

Petrochemical resources

CH_3CHO

HCN+ catalyst

C_3H_5NO

H_2SO_4

Racemic DL lactic acid

Fossil fuel exhaustion
Racemic mixture

Biological production

Renewable resources

Pre-treatment

Fermentable carbohydrates

Microbial fermentation

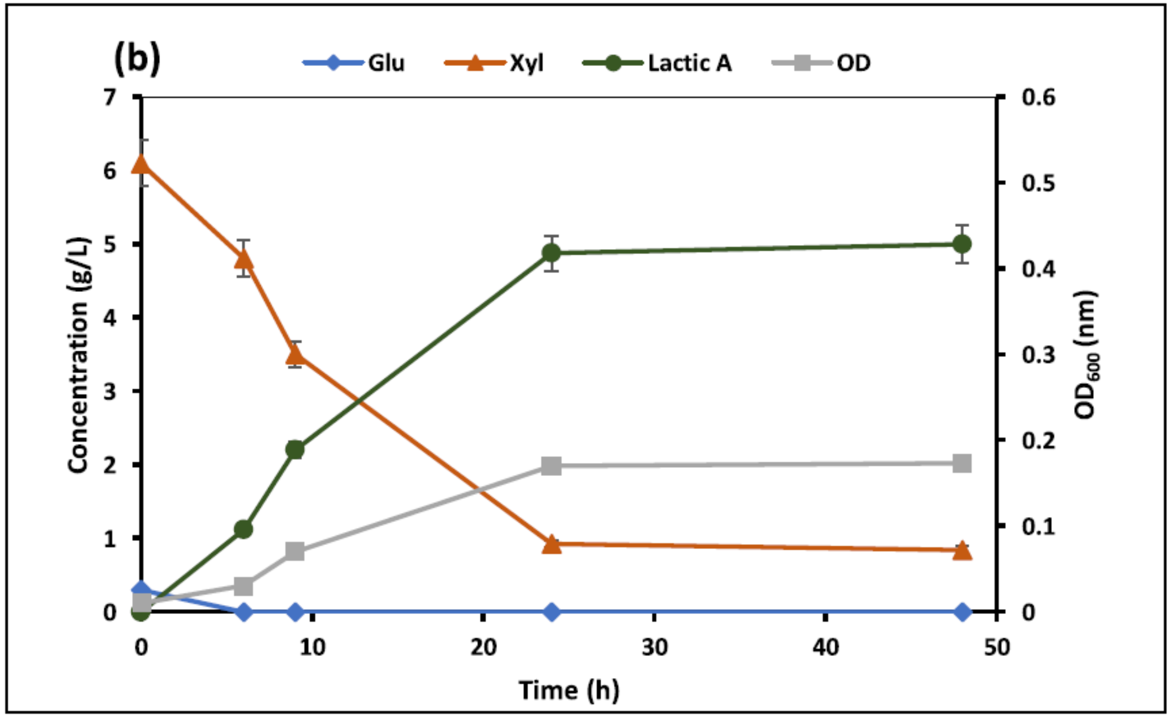
Fermented broth

Recovery and purification

Pure L(+) or D(-) lactic acid

Renewable resources
Pure L(+) or D(-) lactic acid

Ahorsu, PhD, 2021

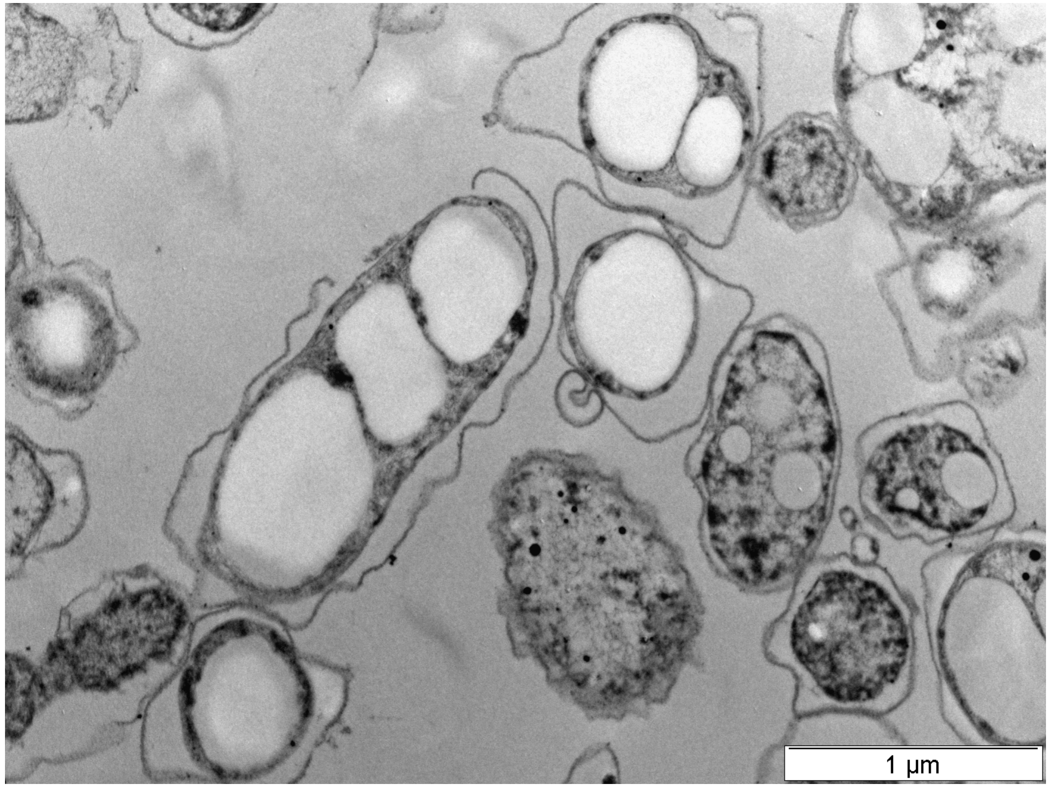


Ahorsu et al, 2019

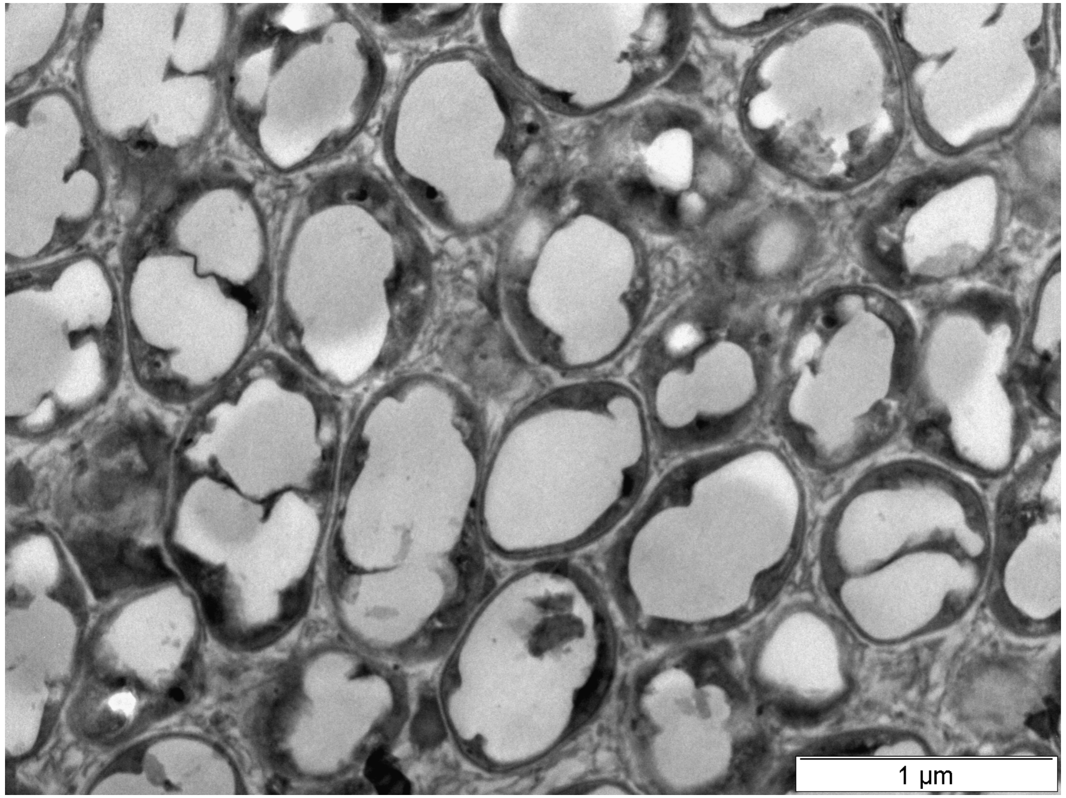
50 g Lactic acid / kg walnut shell

Xylose conversion: 86 %
L-Lactic acid yield: 81 %
Productivity: 0,2 g/L/h

Bacterial PHB from glucose and SCG



Glucose



Spent coffee ground

Polyhydroxyalkanoates Bioplastics: a Sustainable Solution

Polyhydroxyalkanoates (PHAs) are emerging biopolyesters produced by prokaryotic microorganisms from wide range of **renewable feedstocks**

They are only family of the “bioplastics” which are completely biosynthesized and degrade by microorganisms.

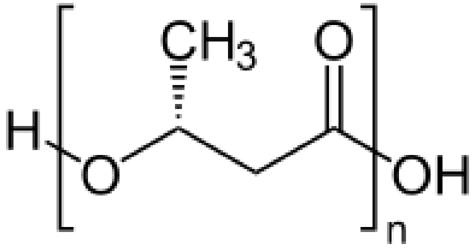
Advantages of Implementation of PHAs to Industrial Applications

- Replace petroleum-based plastics and mitigating environmental challenges caused by petroleum plastics.
- Solve the industrial waste issues.

PHA's: *Cupriavidus necator*
Paraburkholderia sacchari

ure 2.3 Electron microscopic image of *Cupriavidus necator* showing cells with intracellular PHA granules. Magnification 1/70000, from (Koller et al., 2011).

C. necator: Facultative anaerobic, Gram -



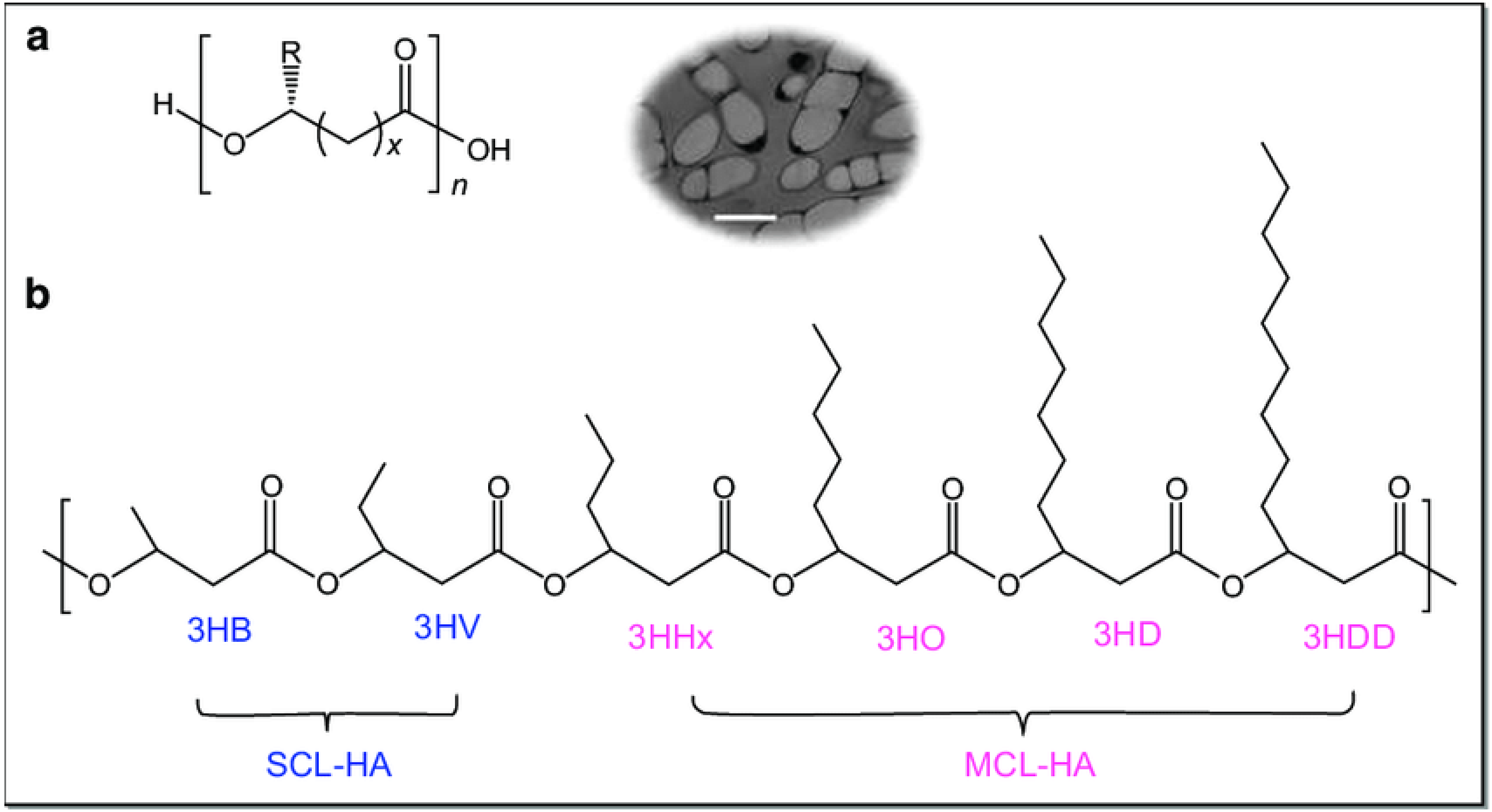
Biodegradable

PP Alternative

Biocompatible, non toxic

Medicine

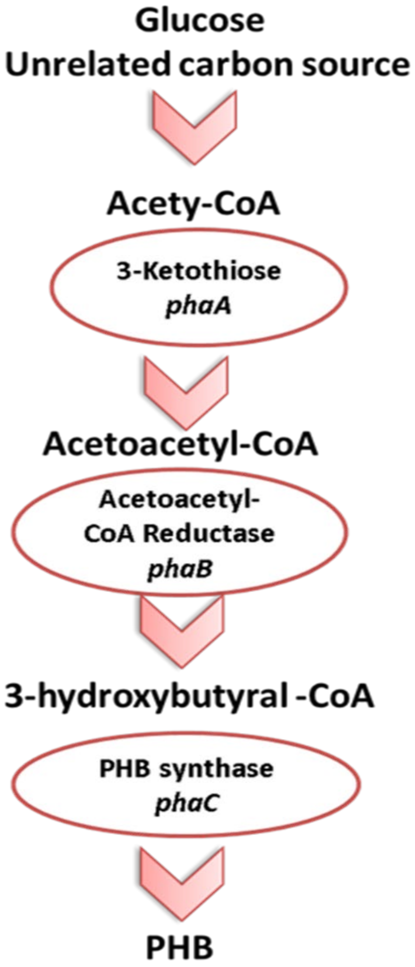
Chemical structure of PHAs



Chemical structures of PHAs : R- methyl (C1) to tridecyl (C13)

Li Z, Yang J, Loh XJ , 2016.

Bacterial production of PHB/PHBV



Glucose
Unrelated carbon source

Acety-CoA

3-Ketothiose
phaA

Acetoacetyl-CoA

Acetoacetyl-CoA Reductase
phaB

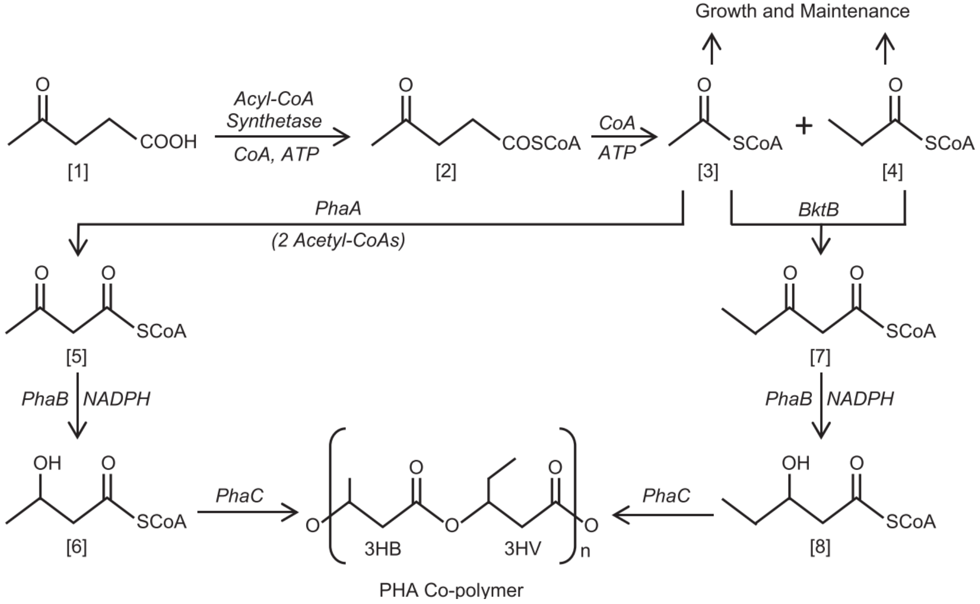
3-hydroxybutyral -CoA

PHB synthase
phaC

PHB

40-60 g PHB / kg SCG

Stressful Conditions: Imbalance of C/N ratio



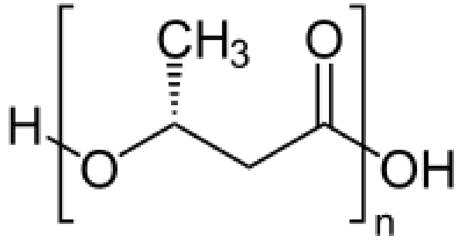
Andhalkar et al., 2024

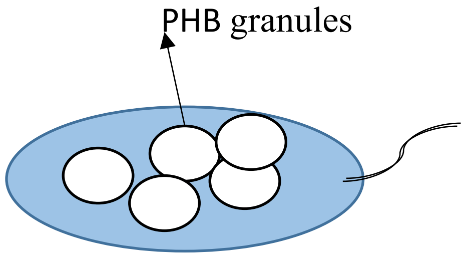
32 g PHBV/kg rice husk

Fig. 1. A suggested metabolic pathway of PHA synthesis from levulinic acid. [1] Levulinic acid; [2] levulinyl-CoA; [3] acetyl-CoA; [4] propionyl-CoA; [5] acetoacetyl-CoA; [6] 3-hydroxybutryl-CoA; [7] 3-ketovaleryl-CoA; [8] 3-hydroxyvaleryl-CoA; CoA, coenzyme-A; ATP, adenosine triphosphate; PhaA, β-ketothiolase A; BktB, β-ketothiolase B; PhaB, NADPH-dependent acetoacetyl-CoA reductase; NADPH, nicotinamide adenine dinucleotide phosphate; PhaC, PHA synthase.

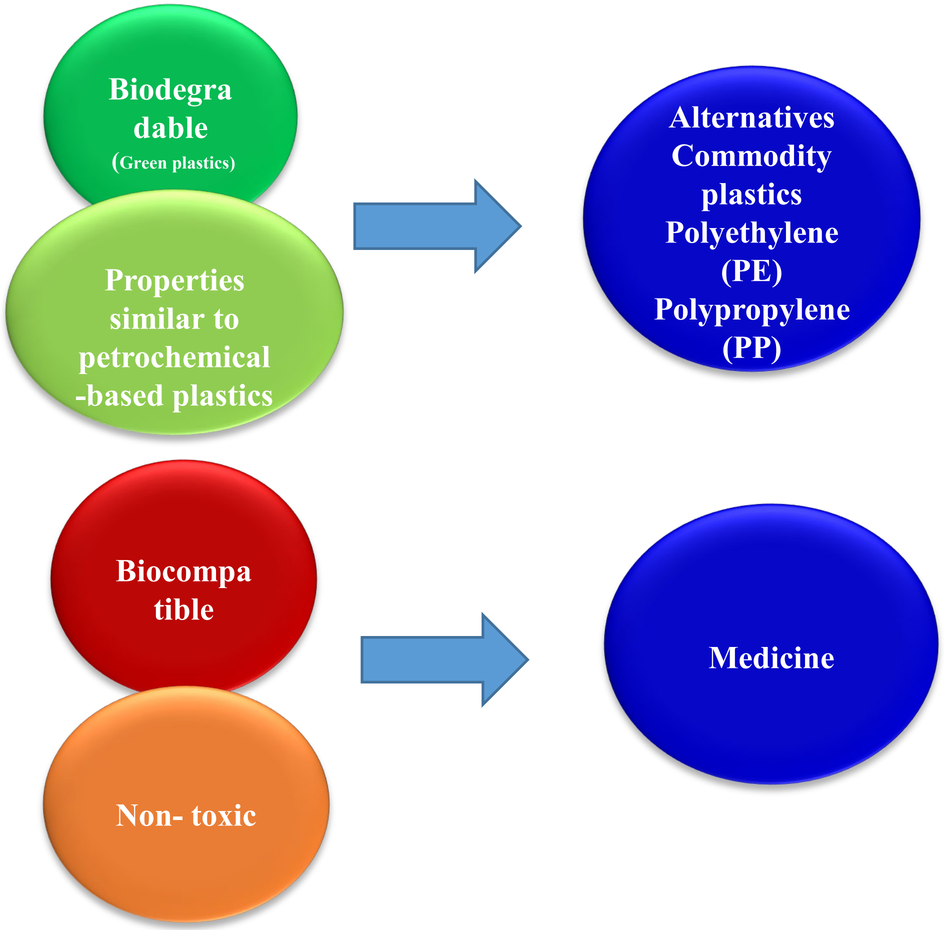
Jaremko, Hawai- J. Biotechnology 155 (2011) 293– 298 /

Accumulation of Bacterial Polyhydroxybutyrate (PHB)





Stress conditions


Biodegradable
(Green plastics)

Properties similar to petrochemical-based plastics

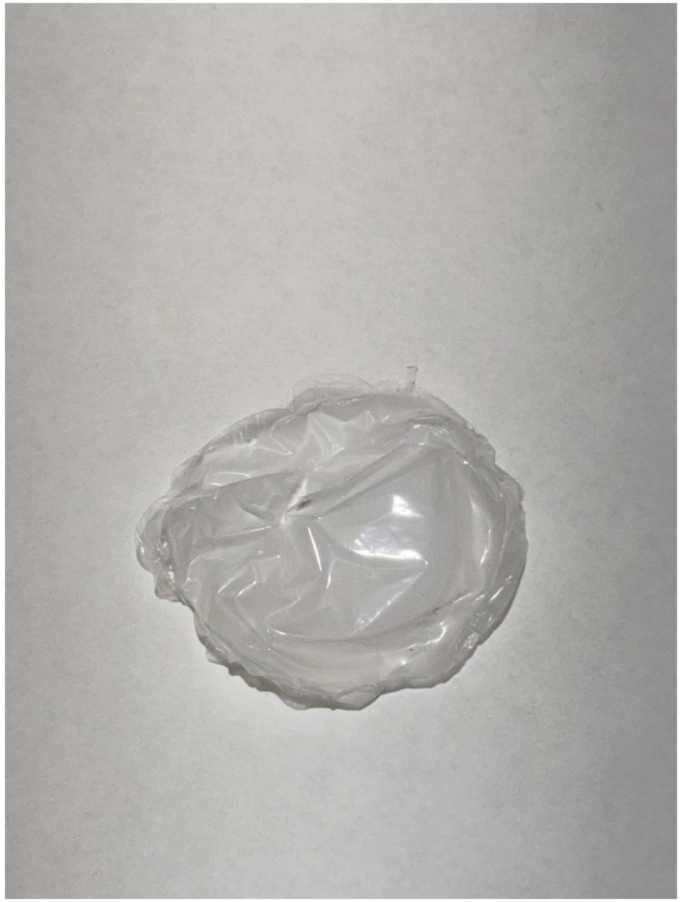
Alternatives Commodity plastics Polyethylene (PE) Polypropylene (PP)

Biocompatible

Non- toxic

Medicine

PHB produced in our laboratories



PHB is BIODEGRADABLE

Biotic degradation (Gangurde et al, 2017)

- Microbial degradation: 18 bacteria + 7 fungi
- 15 days degradation
- 10 days degradation (Environmental liquid that simulates the environment)

Soil microbial communities

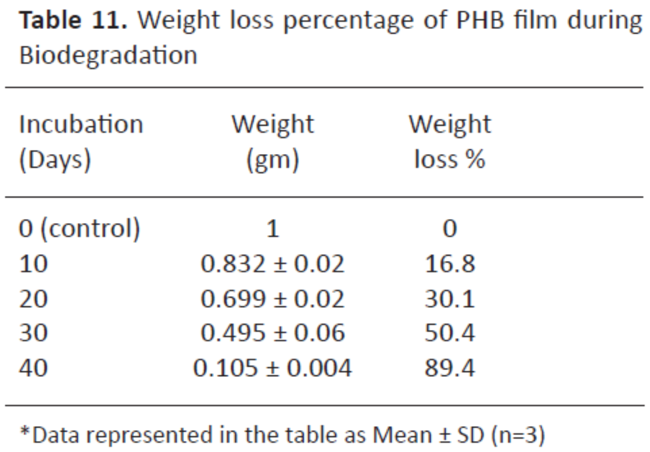


Table 11. Weight loss percentage of PHB film during Biodegradation

Incubation (Days)	Weight (gm)	Weight loss %
0 (control)	1	0
10	0.832 ± 0.02	16.8
20	0.699 ± 0.02	30.1
30	0.495 ± 0.06	50.4
40	0.105 ± 0.004	89.4

*Data represented in the table as Mean ± SD (n=3)

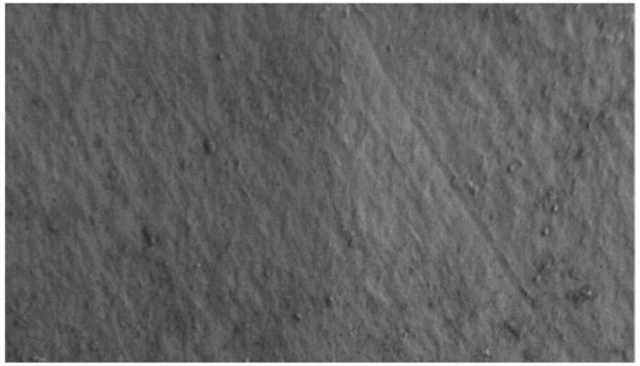


Figure 14. Control – Day 0: Without treatment

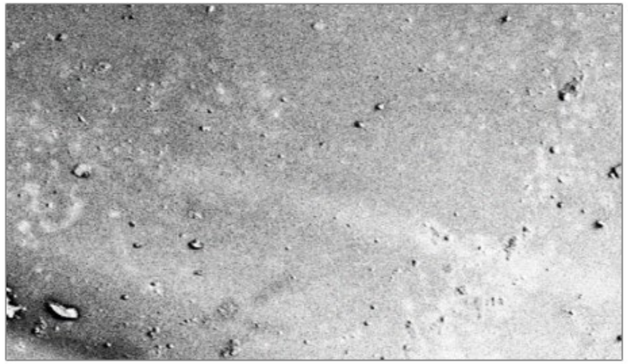
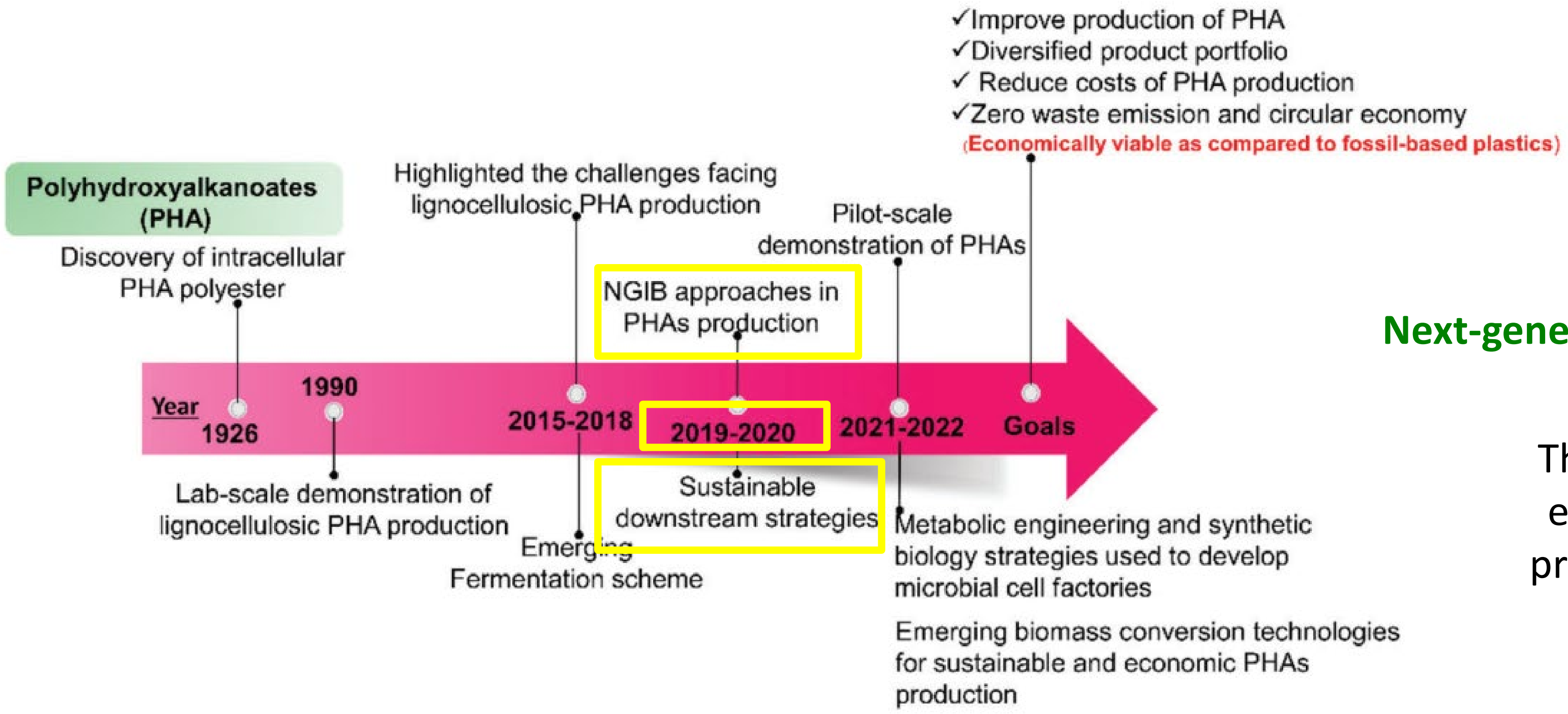


Figure 15. Day 10: During degradation, initial signs of degradation are observed

Figure 18. Day 40: A significant portion of the sheet is degraded, illustrating the culmination of the degradation process

Rathna & Kulandhaivel, 2024

Motivation & Current Challenges



Next-generation industrial biotechnology (NGIB)

The *Halomonas* spp. Successfully engineered to produce multiple products along with PHAs in open and continuous processes

Figure 1. Historical milestones and scientific impact of the development of sustainable and economic PHAs production using lignocellulosic biomass as the raw material

- Downstream processing of PHAs is more complicated and expensive
- Conventional downstream strategies use a large number of halogenated solvents to extract PHAs polyesters from microbial biomass

Andhalkar et al., 2023

Process Integration Approaches

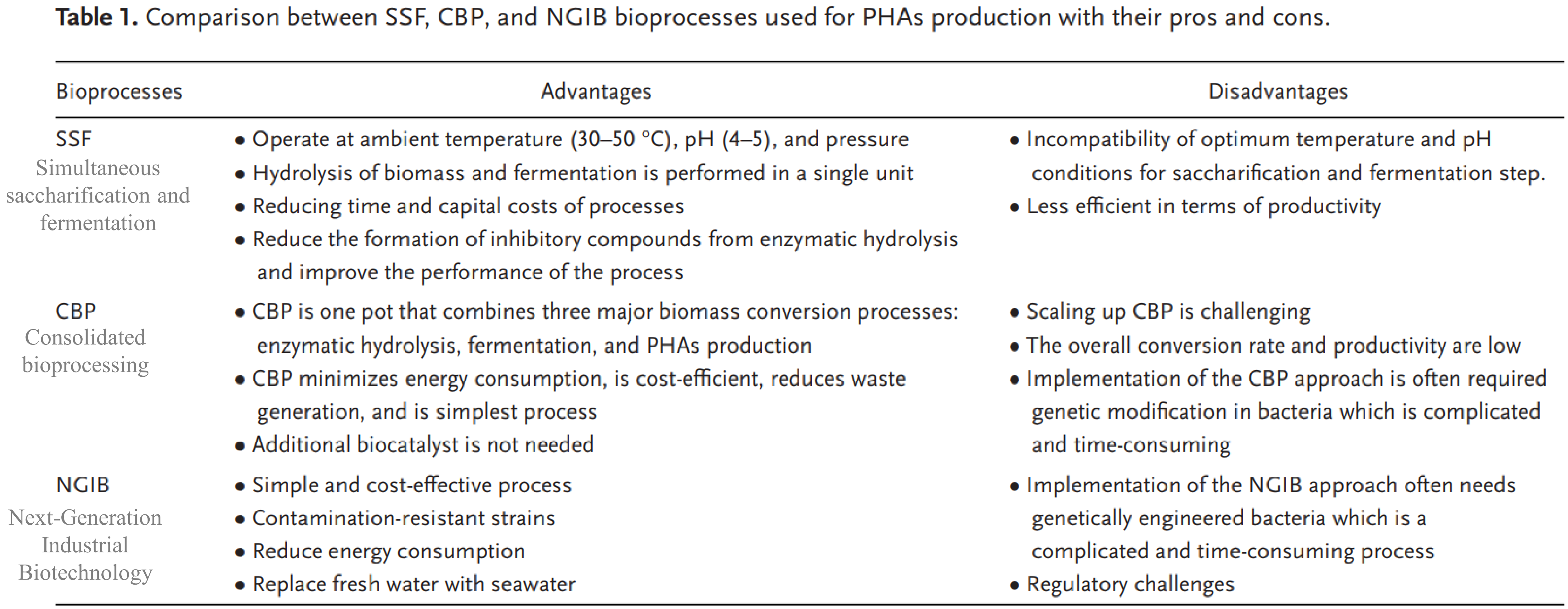


Table 1. Comparison between SSF, CBP, and NGIB bioprocesses used for PHAs production with their pros and cons.

Bioprocesses	Advantages	Disadvantages
SSF Simultaneous saccharification and fermentation	• Operate at ambient temperature (30–50 °C), pH (4–5), and pressure • Hydrolysis of biomass and fermentation is performed in a single unit • Reducing time and capital costs of processes • Reduce the formation of inhibitory compounds from enzymatic hydrolysis and improve the performance of the process	• Incompatibility of optimum temperature and pH conditions for saccharification and fermentation step. • Less efficient in terms of productivity
CBP Consolidated bioprocessing	• CBP is one pot that combines three major biomass conversion processes: enzymatic hydrolysis, fermentation, and PHAs production • CBP minimizes energy consumption, is cost-efficient, reduces waste generation, and is simplest process • Additional biocatalyst is not needed	• Scaling up CBP is challenging • The overall conversion rate and productivity are low • Implementation of the CBP approach is often required genetic modification in bacteria which is complicated and time-consuming
NGIB Next-Generation Industrial Biotechnology	• Simple and cost-effective process • Contamination-resistant strains • Reduce energy consumption • Replace fresh water with seawater	• Implementation of the NGIB approach often needs genetically engineered bacteria which is a complicated and time-consuming process • Regulatory challenges

- SSF: single unit for hydrolysis + fermentation (moderate efficiency)
- CBP: one-pot pretreatment–fermentation (20–40% cost reduction)
- NGIB: open, continuous system (cost-effective, robust)

Andhalkar et al., 2023

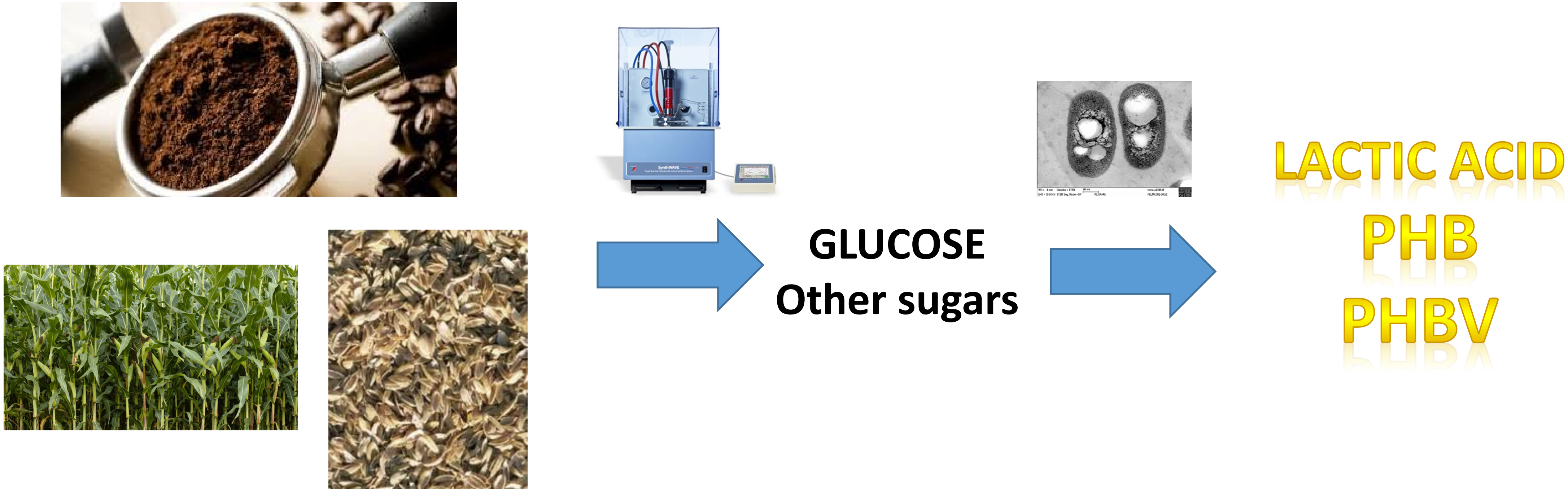
Importance of LCA in PHAs

- PHAs are biodegradable alternatives to fossil plastics (PET, PP, PE)

- LCA evaluates:
  - Energy demand in upstream (feedstock cultivation)
  - Energy demand in downstream (extraction & purification)

- Evolution of LCA focus:
  - 2000s: Compare with oil-based plastics.
  - 2010s–2020s: Compare different feedstocks and process configurations.

Summary:



GLUCOSE

Other sugars

LACTIC ACID

PHB

PHBV

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Thanks for your attention

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