



Hanze
University of Applied Sciences
Groningen



Biobased
Economy

NHL
STENDEN

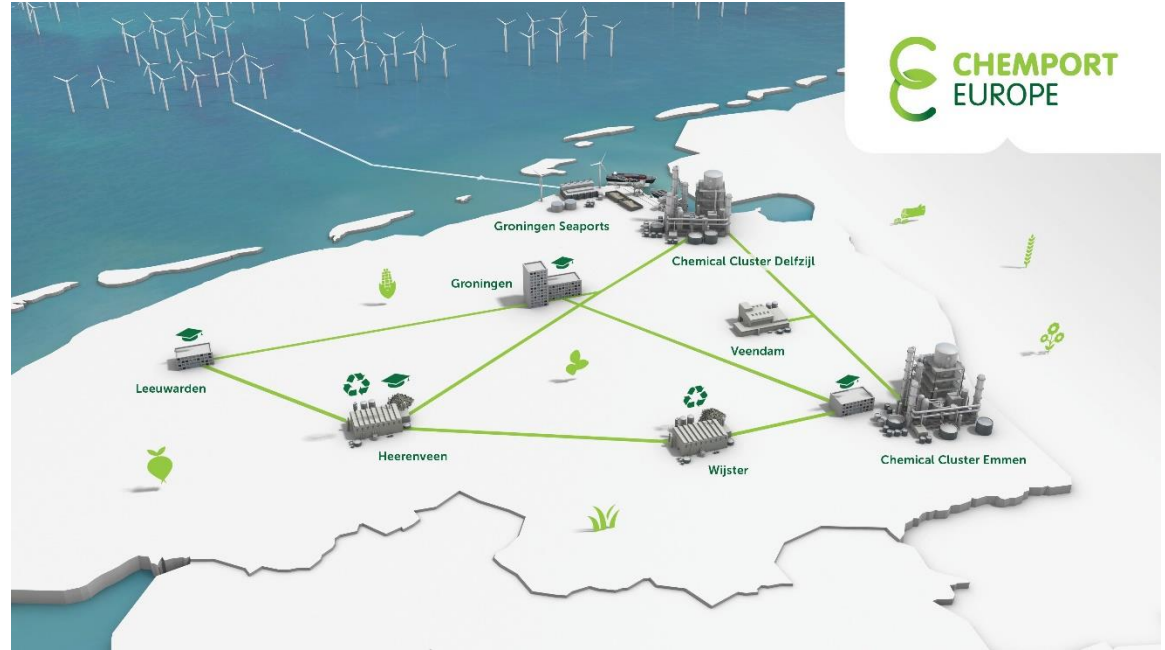
Green PAC
Polymer Application Centre

Circularity & end of life of PHA

Erik Keller KCBBE , Corinne van Noordenne NHL Stenden

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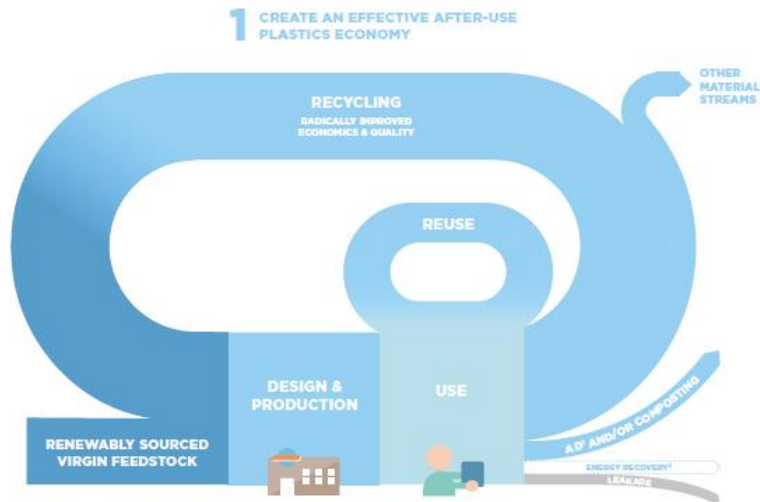
Introduction Hanze and NHL



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THE NEW PLASTICS ECONOMY PROPOSES A NEW WAY OF THINKING

The vision of the New Plastics Economy is that plastics never become waste; rather, they re-enter the economy as valuable technical or biological nutrients.



3 DECOUPLE PLASTICS FROM FOSSIL FEEDSTOCKS

¹ Anaerobic digestion
² The role, of, and boundary conditions for, energy recovery in the New Plastics Economy need to be further investigated
 Source: Project Mainstream analysis.

2 DRASTICALLY REDUCE THE LEAKAGE OF PLASTICS INTO NATURAL SYSTEMS & OTHER NEGATIVE EXTERNALITIES

Renewable carbon can come from the

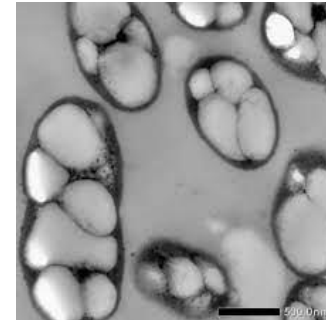
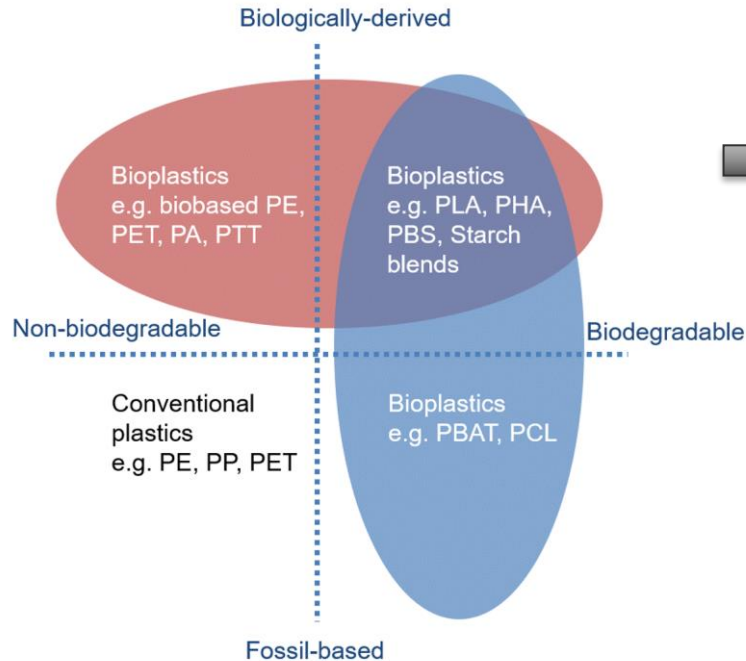
- Biosphere** (parts of the Earth where life exists)
- Atmosphere** (the gases surrounding the Earth)
- Technosphere** (part of the environment which is made or modified by humans)

But not from the

- Geosphere** (the Earth itself)

[New Plastics Economy Reports \(ellenmacarthurfoundation.org\)](https://ellenmacarthurfoundation.org)

(Bio)plastics



Polyhydroxyalkanoates (PHA)
(energy storage)

Polyhydroxyalkanoates (PHA)

PHA bioplastics are biodegradable in compost, like other bioplastics, but also in free water, a unique property thanks to the metabolic activity of microorganisms naturally present in the environment.

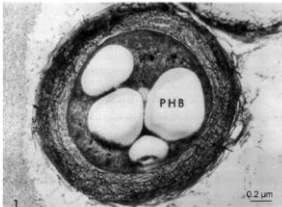
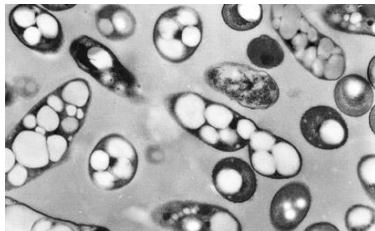
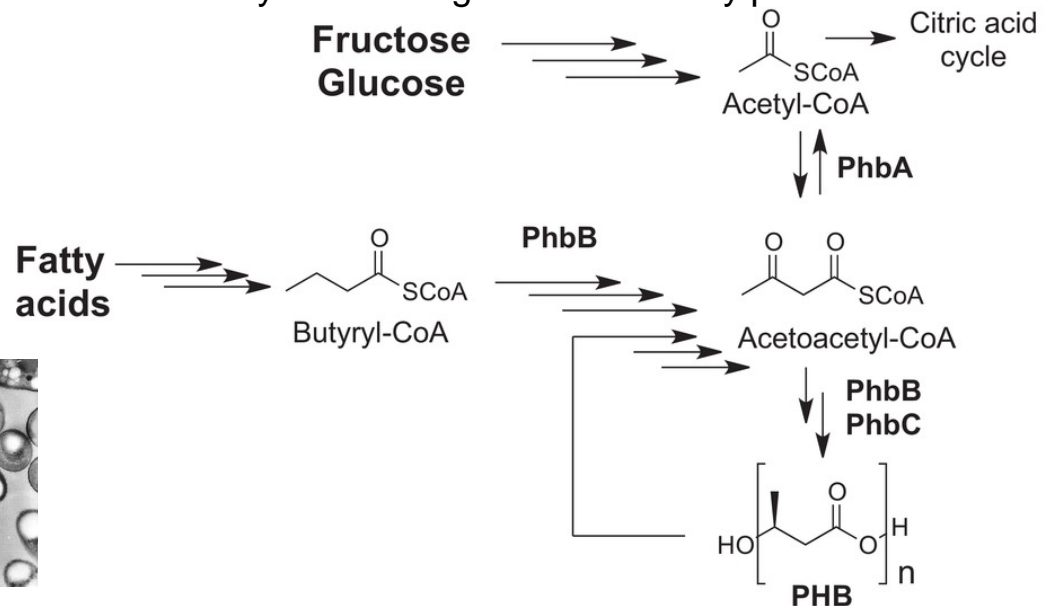


Fig. 1. Electron micrograph of a thin section of a mature cyst of *Azotobacter vinelandii* containing poly-(R)-3-hydroxybutyrate (PHB) granules [1]

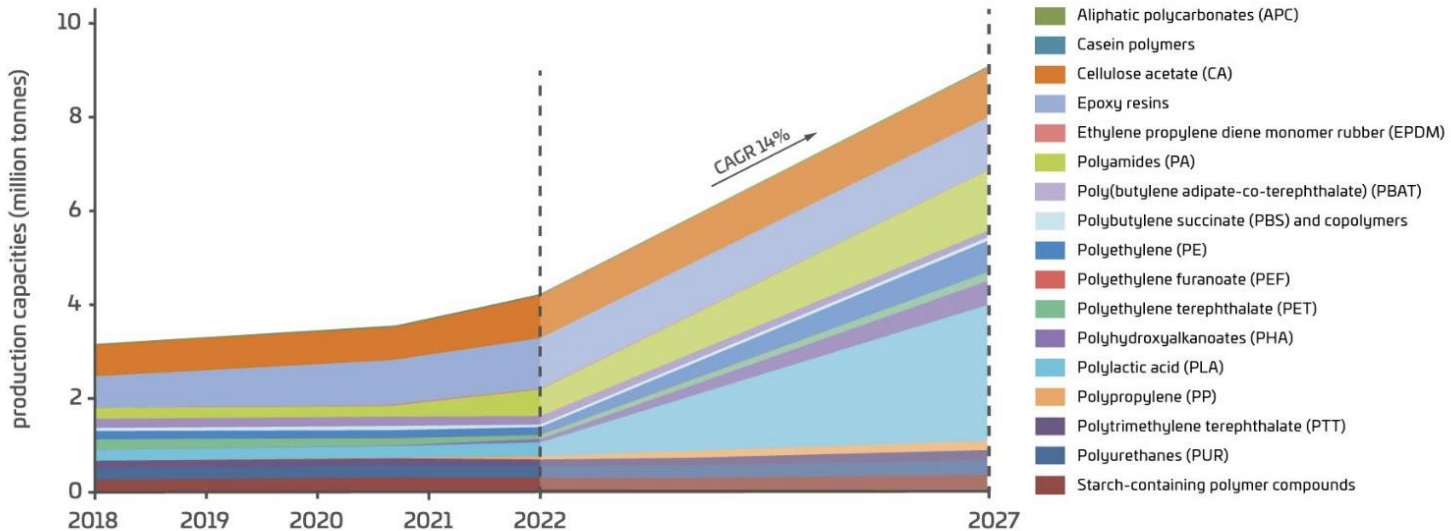


“Carbonosomes”



Bio-based Polymers

Evolution of Worldwide Production Capacities from 2018 to 2027



available at www.renewable-carbon.eu/graphics

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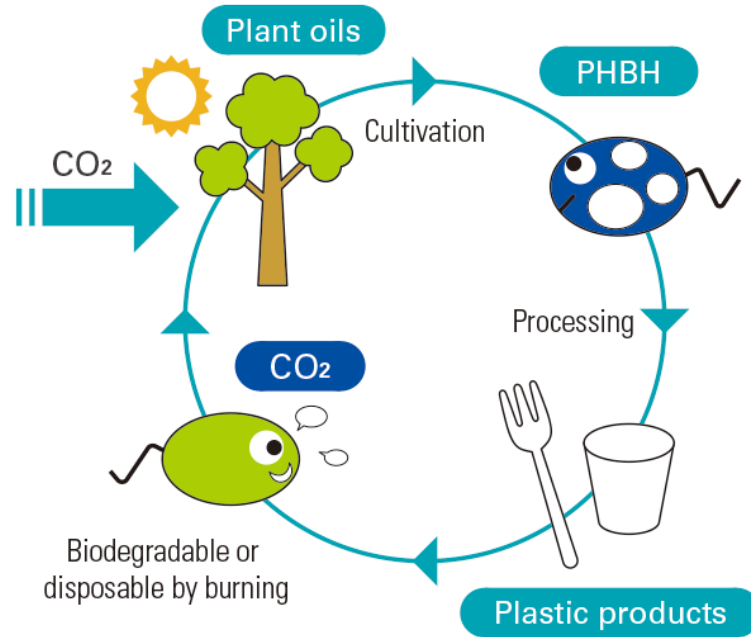
PHA biopolymers with a bright future

The replacement of fossil-based plastics by PHAs will increase considerably

Recycling strategies need to be developed for polyhydroxyalkanoate end of life material

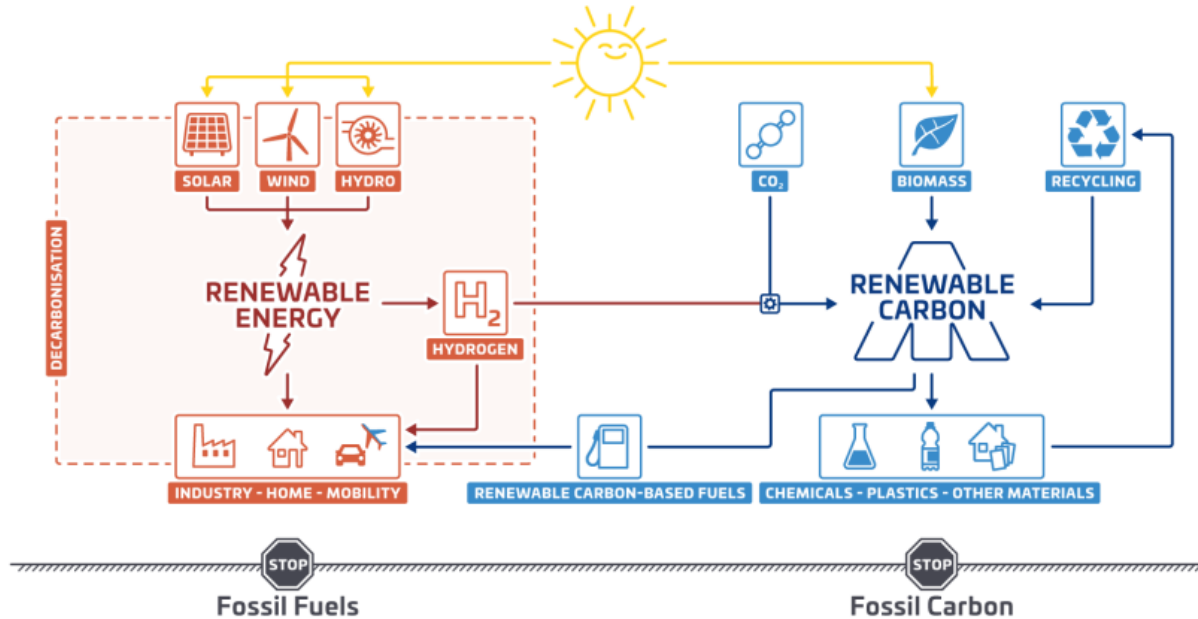
Links between material composition and ease of recycling need to be unveiled.

Circular plastic



Source Kaneka

Renewable Energy and Renewable Carbon for a Sustainable Future



All figures available at www.bio-based.eu/graphics

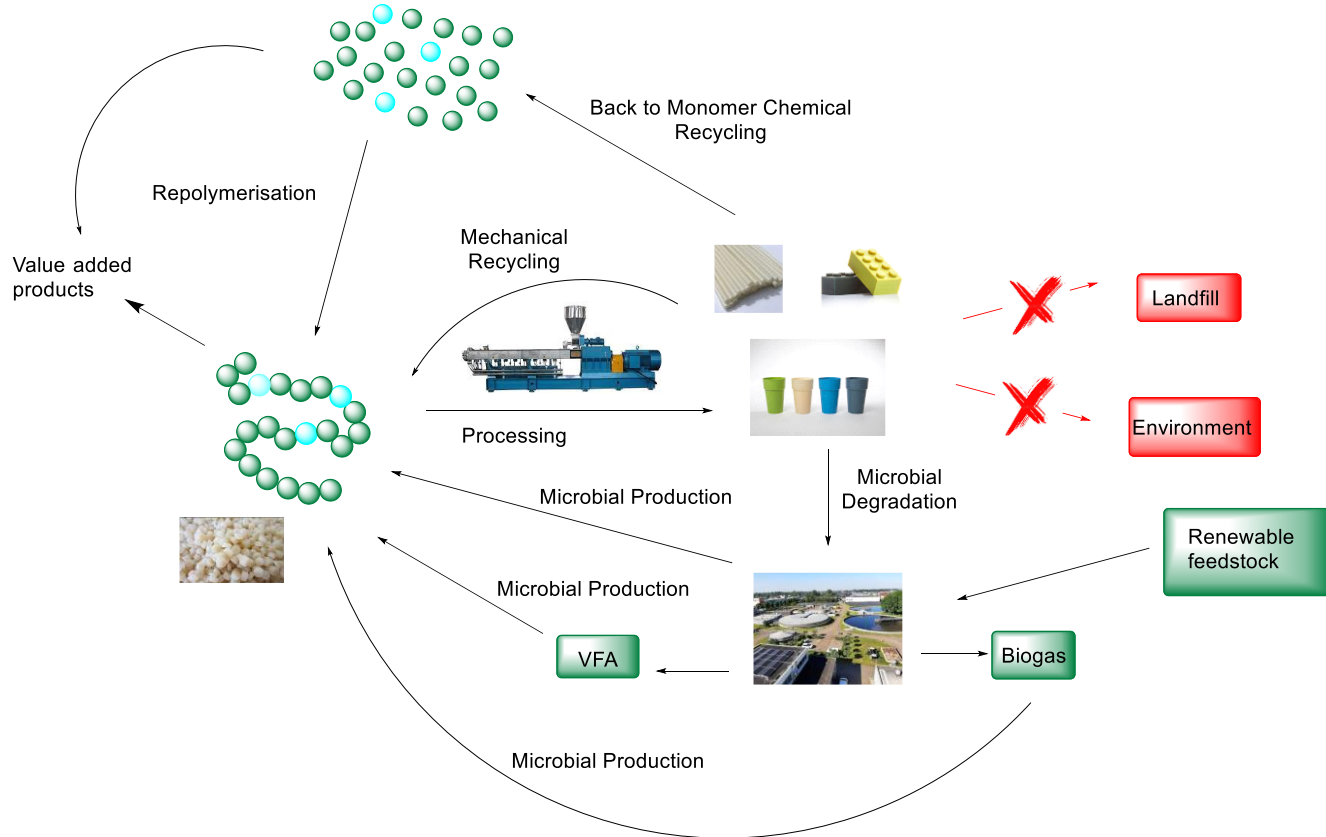
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Recycling of PHA

Keeping carbon in the loop



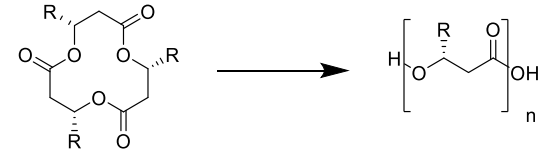
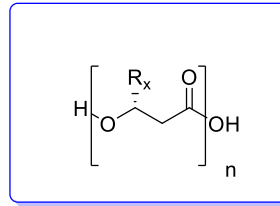
Recycling Strategies for PHA



PHA @ Hanze University of Applied Sciences

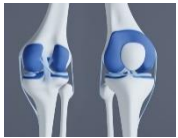
sample_id	Source	Label	percentage 3HB	percentage 4HB	percentage PHB/VH	Mp	Mn	Mw	Tm_C
s11	Miral	PHB 841100	99,7	0,0	0,3	38796	21158	87428	168,3
s12	Natureplast	PHB 002	99,8	0,0	0,2	135455	86819	187892	162,8
s13	Emmat	Emmat Y1000p	99,8	0,0	1,2	168572	81881	197731	168,8
s14	Miral	PHB 842100	92,2	5,8	1,9	101076	75098	166619	169,54
s15		PHB 1330	84,5	15,5	0,0	40734	20281	45371	166,9
s16	Kaneka	X111A	91,3	0,0	8,7	266149	117538	311120	146,8
s17	Kaneka	X121A	86,5	0,0	13,5	192843	105108	247139	140,1
s18		YK100B31-1	63,0	35,8	1,2	45205	34446	94437	170,4
s19		Ecovene	71,7	21,1	5,2	77837	64853	95294	143,5
s10		YK100B31-2	61,6	35,3	3,1	45205	34446	94437	169,7
s11		Atox 1400res	100,0	0,0	0,0	nd	nd	nd	174,5
s12	Kaneka	K513N	90,4	0,0	9,6	118380	88657	188430	145,9
s14	Danimer	402120	95,0	0,0	5,0	233796	131572	344023	145,43
s15	Danimer	402135	99,8	0,0	0,2	342848	187312	476248	163,57

- Analysis, properties/applications



R = Me

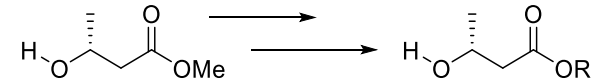
- Chemical Recycling



- Medical devices



- Production and sustainable down stream processing

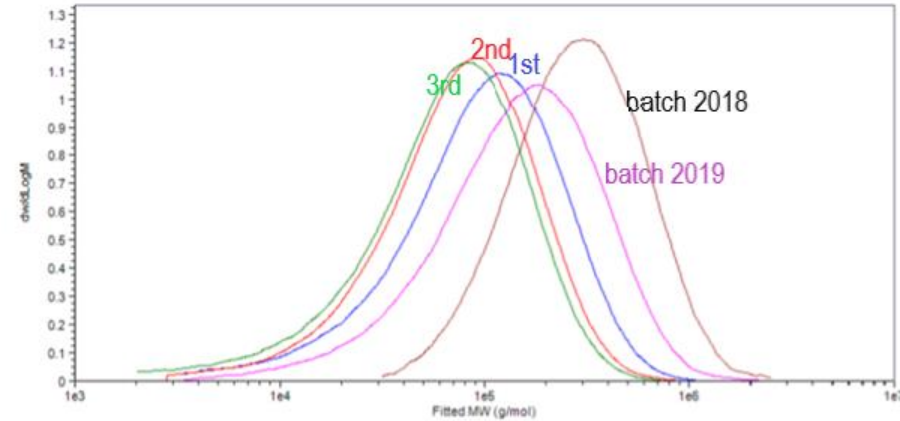
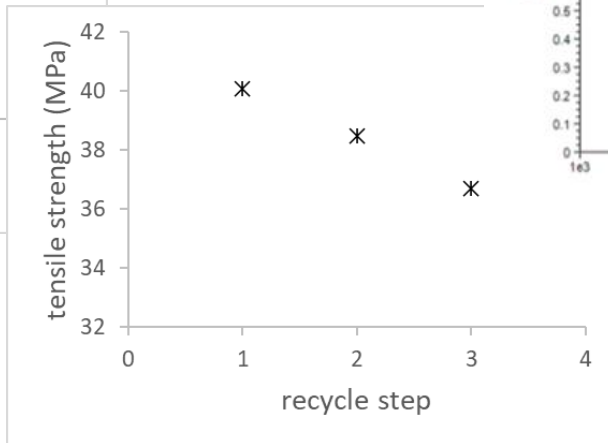
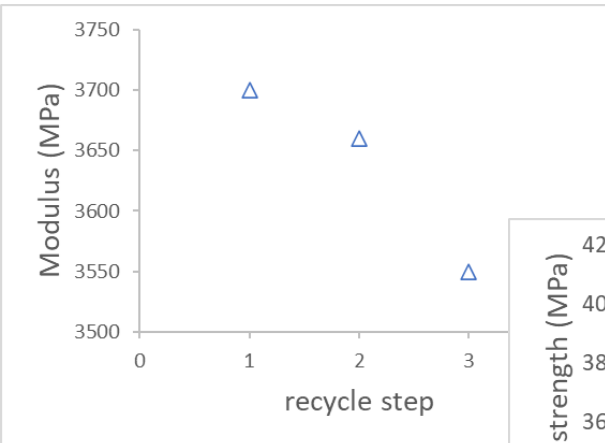


- Ketones bodies

Mechanical recycling

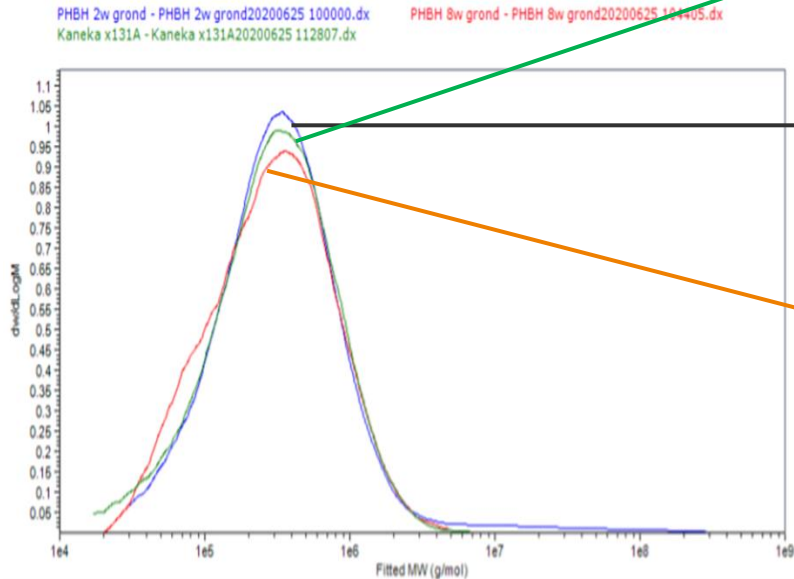
Enmat Y1000P

Injection molding, testing, shredding, injection molding....



Biodegradation/disintegration in soil

Molecular Weight Distribution Plots

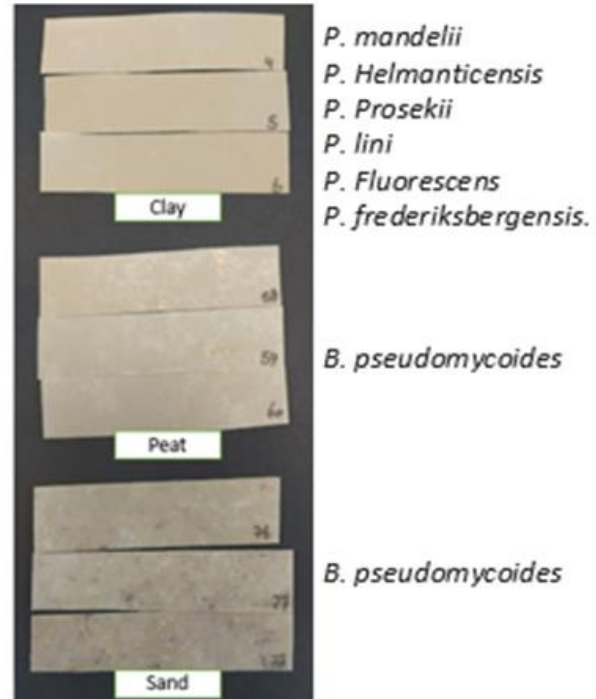
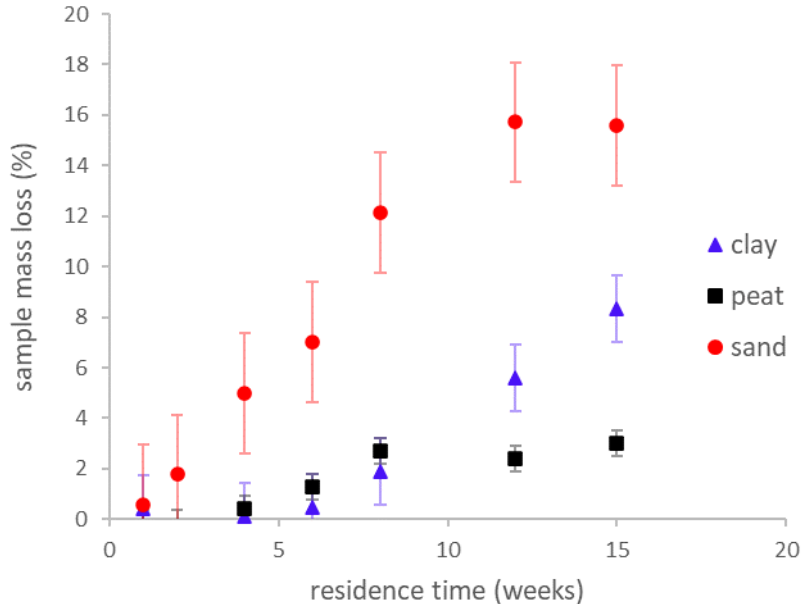


	PHBH
Start material	
1 week	
2 weeks	
4 weeks	
8 weeks	
16 weeks	















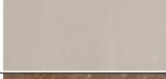
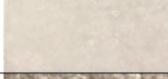
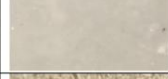










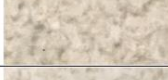





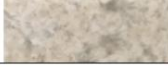




Biodegradation/disintegration

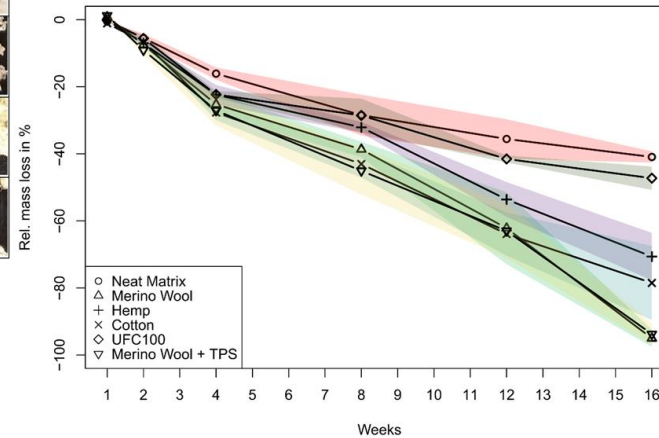
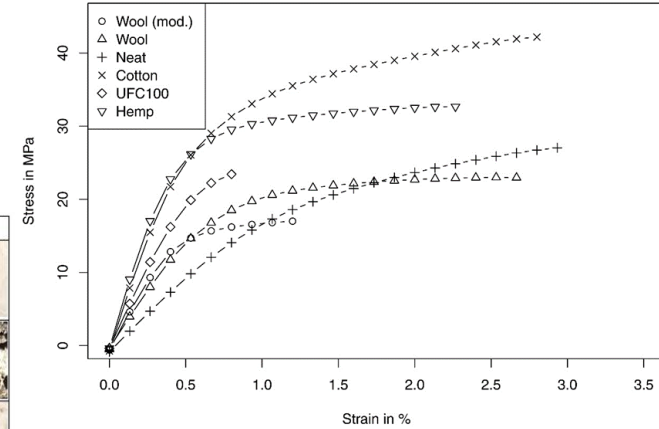
Influence of soil type



Biodegradation/disintegration

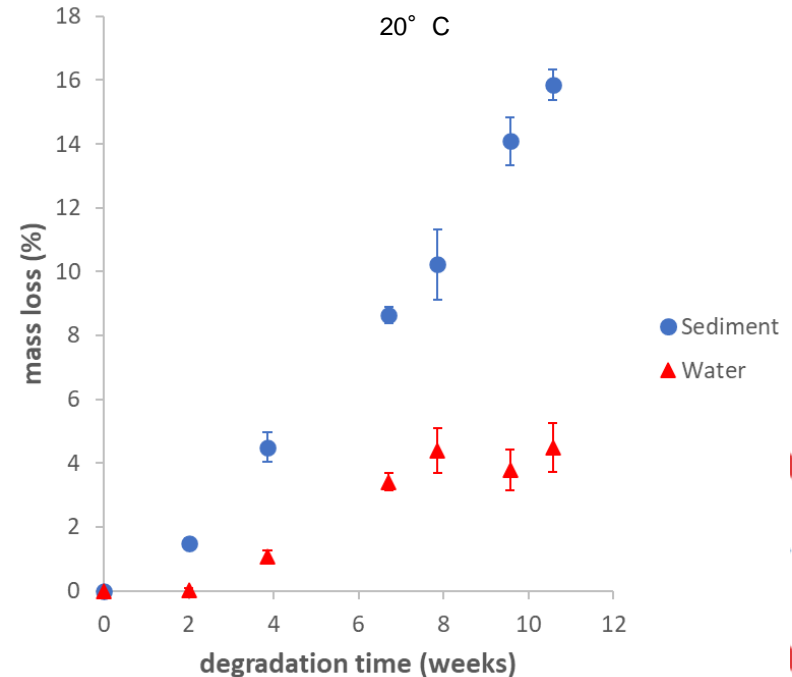
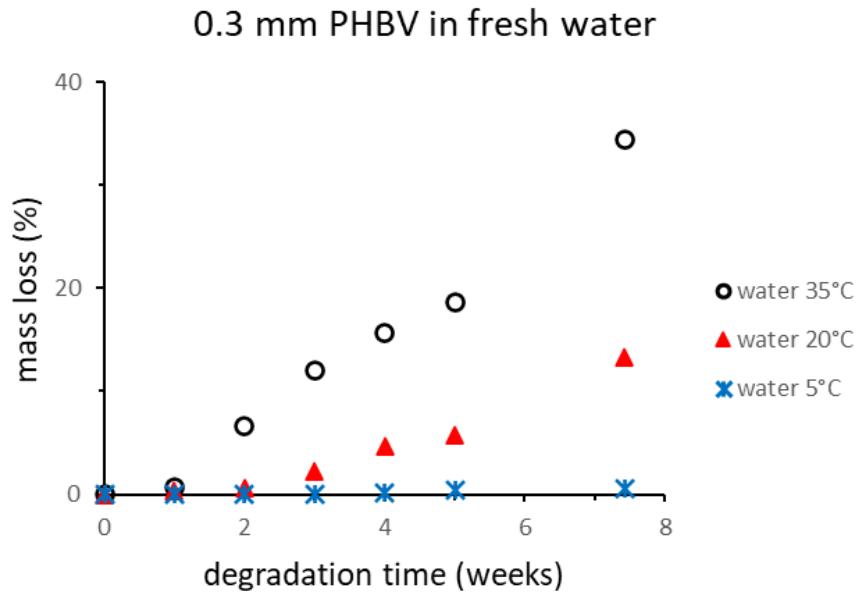
Influence of natural fibers

	start	1 week	2 weeks	4 weeks	8 weeks	16 weeks
PHBH X331N						
PHBH X331N + 30% Cotton						
PHBH X331N + 30% UFC100						
PHBH X331N + 30% Hemp						
PHBH X331N + 30% Wool						
PHBH X331N/Nuvolve +30% Wool						

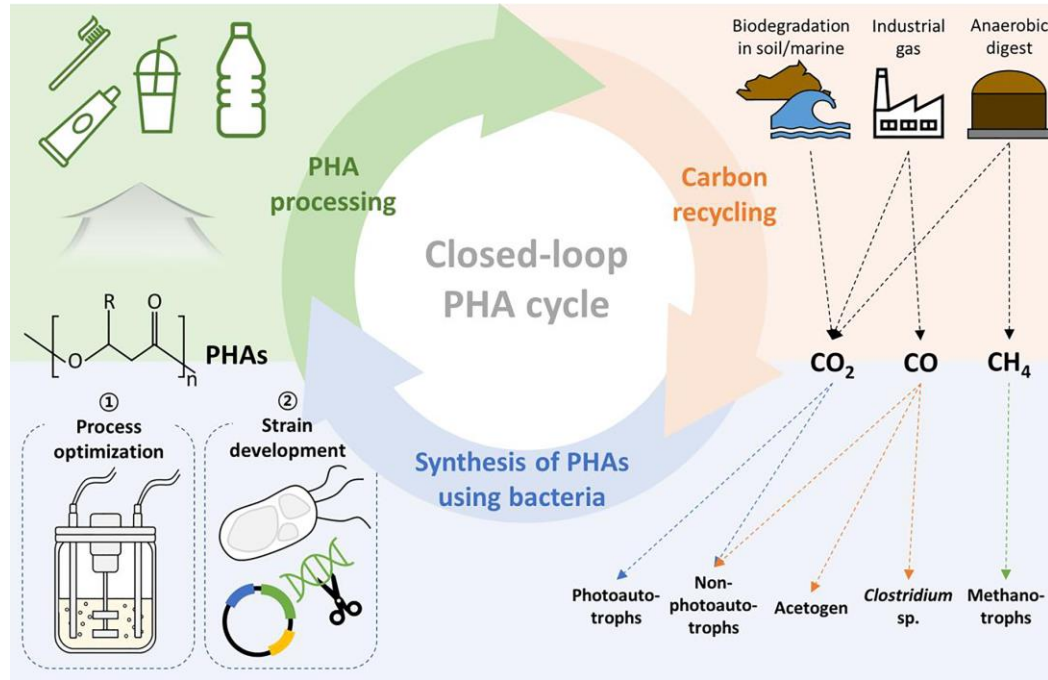


Biodegradation/disintegration

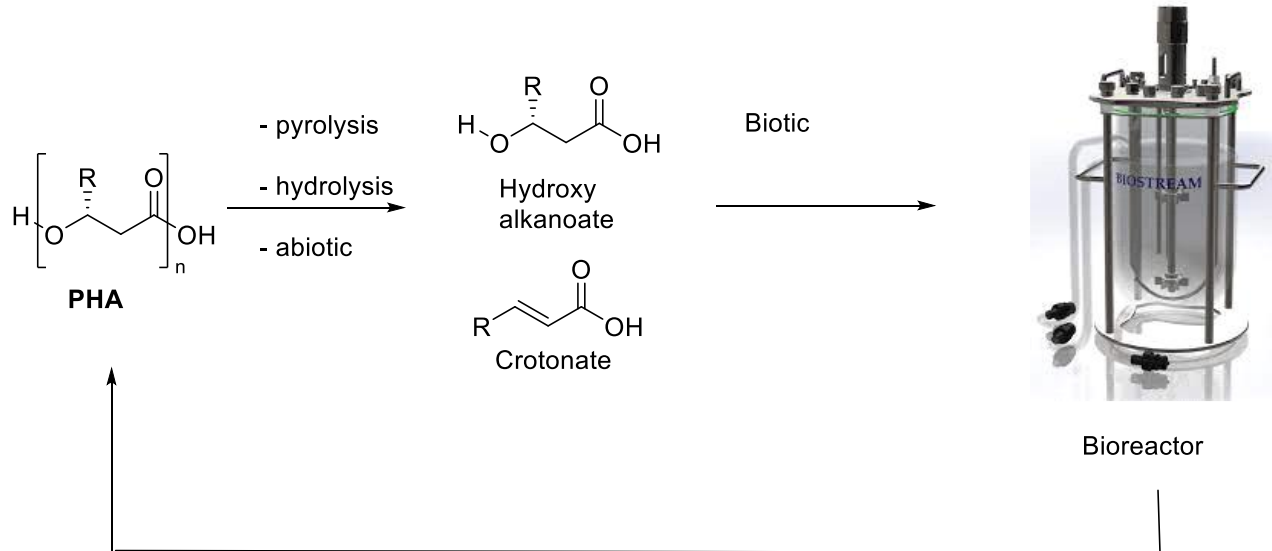
Fresh water; temperature and sediment



Biosynthesis of C1 gas-derived PHA



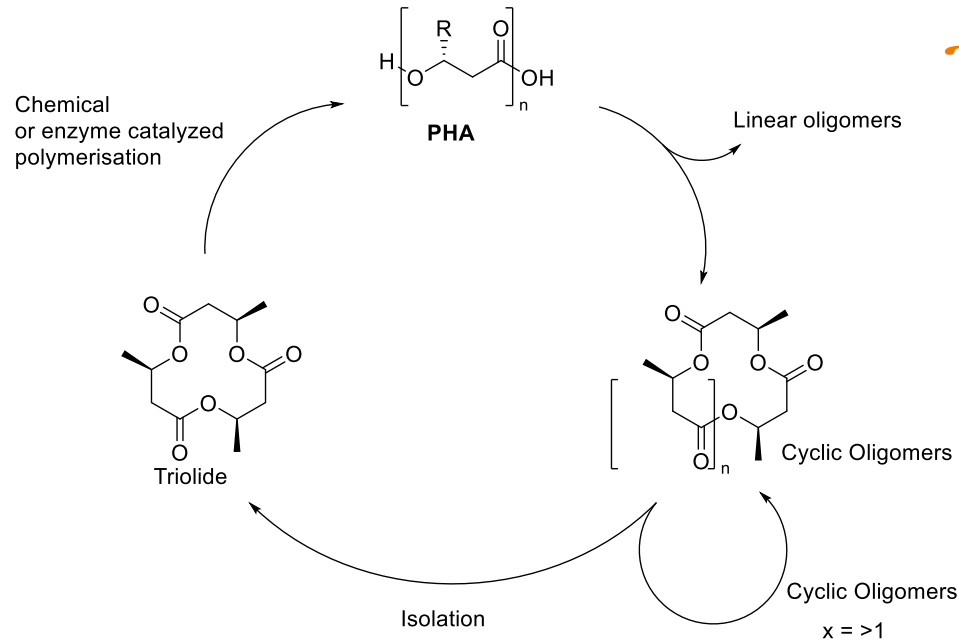
Direct recycling of PHA from waste PHA



dx.doi.org/10.1016/j.biortech.2014.07.105

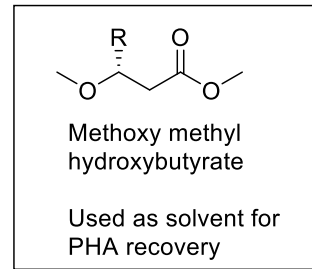
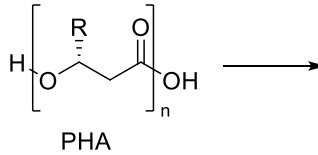
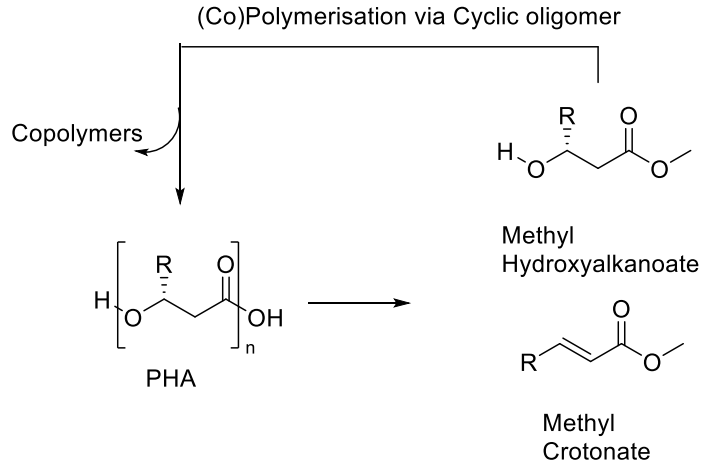
doi.org/10.1007/s10924-018-1347-8

Thermodynamic recycling via ring closing depolymerisation and ring opening polymerisation (ROP)



Possibilities for Copolymerisation using for example Lactide or Caprolactone

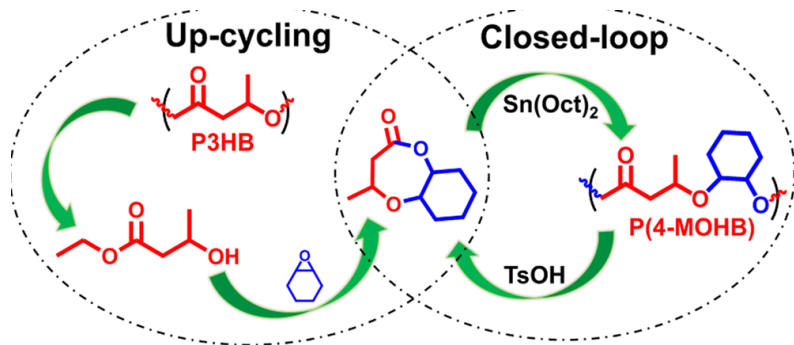
Solvolytic recycling and upcycling of PHA



Parodi *et al* doi.org/10.1021/acssuschemeng.1c03299
Don *et al* doi.org/10.1007/s10965-017-1432-z

Chemical Upcycling of Poly(3-hydroxybutyrate) into Bicyclic Ether

doi.org/10.1021/acssuschemeng.2c02124





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