



Turning PHA wastes to biofuel

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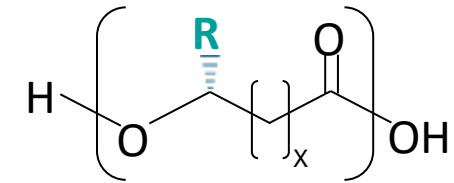
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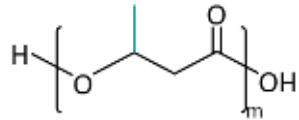
Polyhydroxyalkanoates (PHAs)

A natural & diverse polyester family



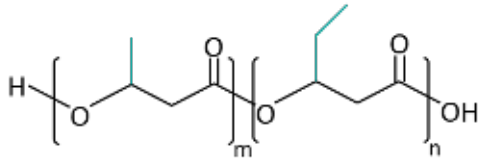
Short-chain-length (scl-) PHAs

P3HB



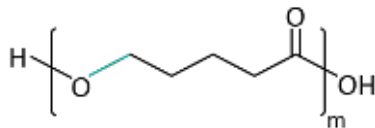
Homopolymer,
branched

P(3HB/3HV)



Copolymer,
branched

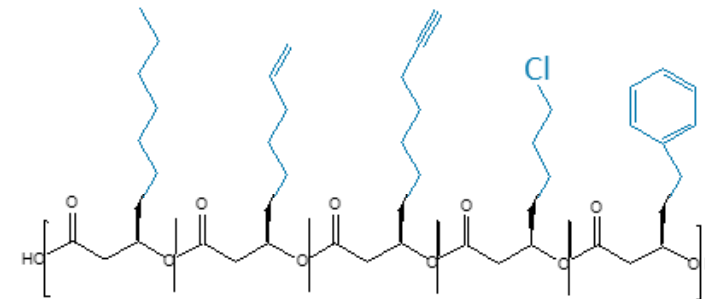
P4HB



Homopolymer,
linear

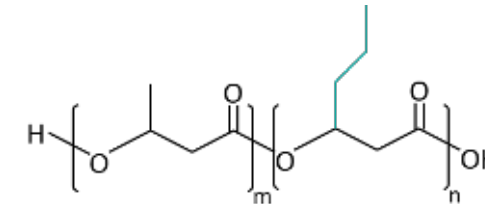
- Thermoplasts
- High crystallinity (40-80%)
- Density > 1.2 g cm⁻³
- Low elongation at break
- Industrial scale

Medium-chain-length (mcl-) PHAs



Large variety of
monomers
(side chain, R)

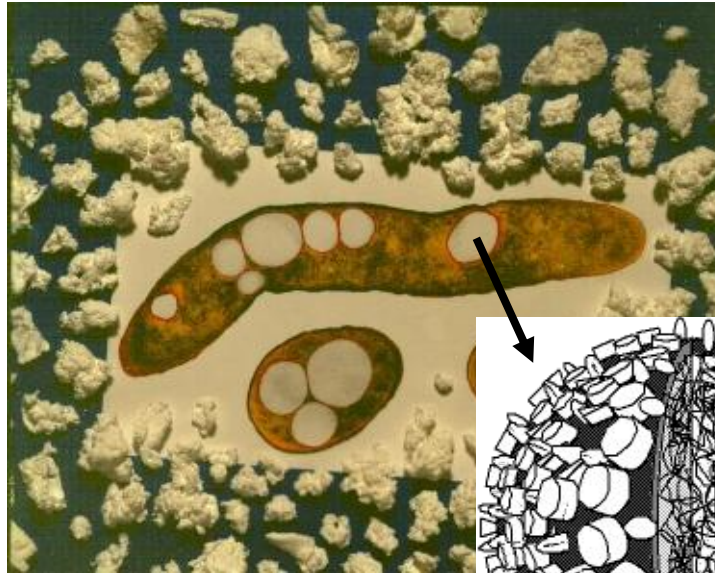
PHBHHx



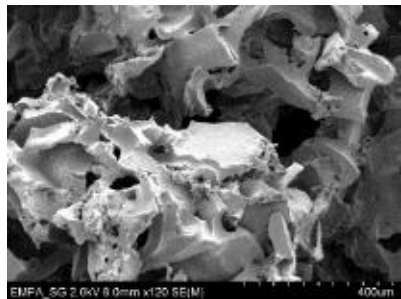
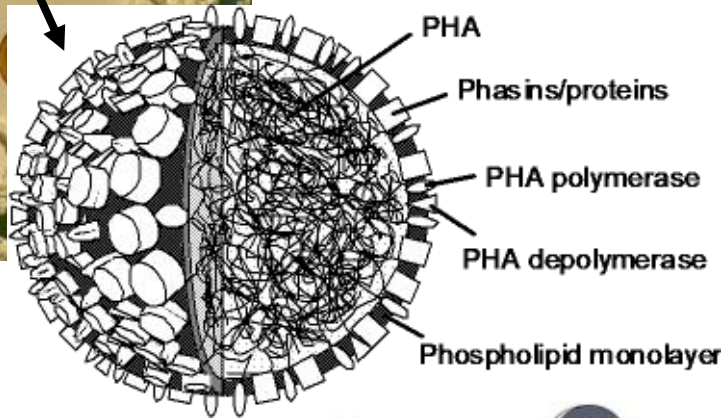
- Elastomeric, thermoplastic, duroplastic or fluidoplastic properties
- Low crystallinity (0-40%)
- Density: ca. 1.05 g cm⁻³
- Elongation at break adjustable (>100%)
- Industrial scale: PHBHHx

PHA: biosynthesis of bacterial polyester and processing

Poly(3-hydroxybutyrate) (PHB) produced via fermentation



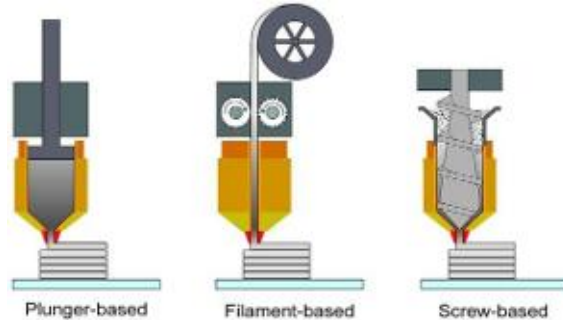
Cupriavidus necator
Poly(3-hydroxybutyrate) (PHB)



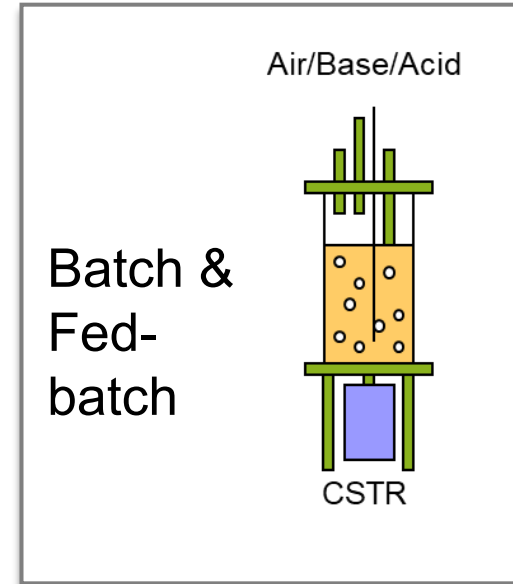
Foam & porous structures



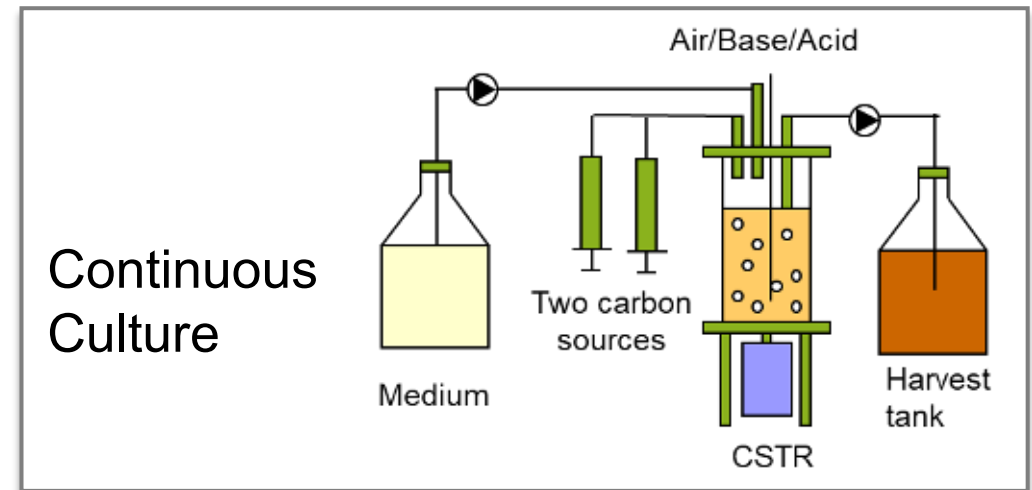
Fibers



Additive manufacturing



Batch &
Fed-
batch



Continuous
Culture

PHA Development

Global Production capacities of bioplastics 2024-2029 in 1,000 tonnes



Adhesives



terraverdae.com

3D printing for industrial prototyping



terraverdae.com

Elastomers



Packaging



pha-sourcing.com

Cosmetics



«Pure today AHA/PHA Peeling Cleanser» (purish.com)



helianpolymers.com

Paint & lubricants

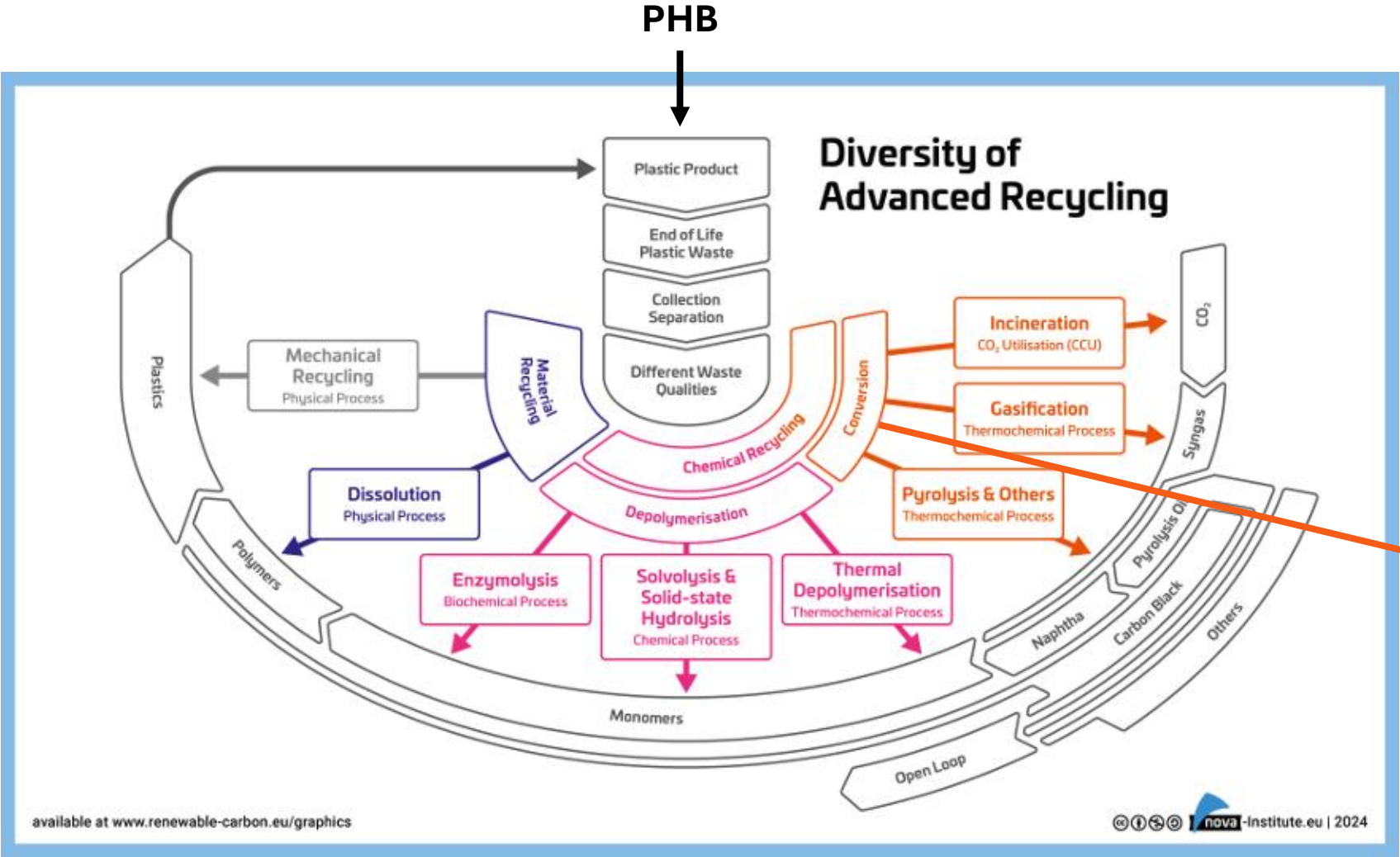


Agriculture Horticulture



salesplastics.com

Recycling of PHAs

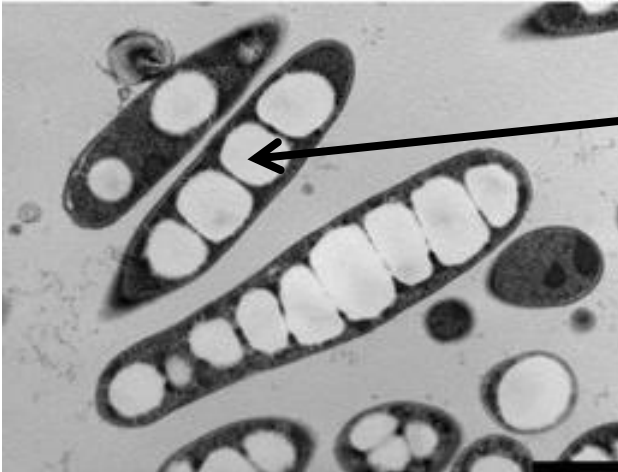
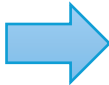


B3HB:
- biofuel
- solvent

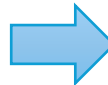
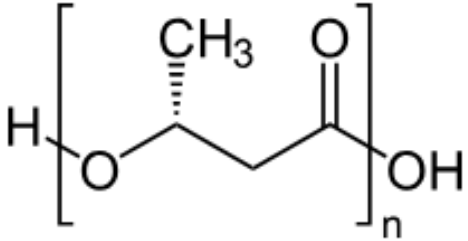
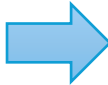
Overview



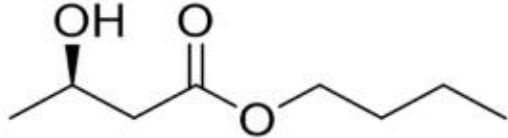
Feedstock
Water
Nutrients
Energy



**Poly(3-hydroxybutyrate)
PHB**

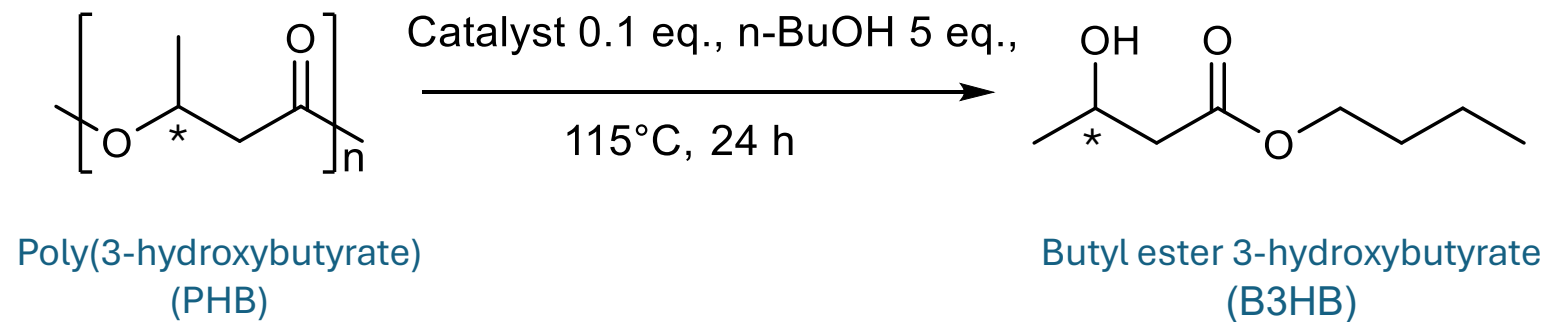


**Butyl ester
3-hydroxybutyrate
B3HB**



Synthesis of B3HB

- Based on classical protocols, PHB is treated with n-butanol and an Bronsted (e.g., H₂SO₄-ionic liquid) or Lewis acid (e.g., FeCl₃) catalyst.
- The formed n-butyl 3-hydroxybutyrate helps in solubilization of the PHB increasing process efficiency
- The excess n-butanol can be distilled after reaction, followed by the biofuel
- In case of using acidic ionic liquids, the catalyst can be re-used
- The reaction was scaled to 5L and is being scaled at 100 L.

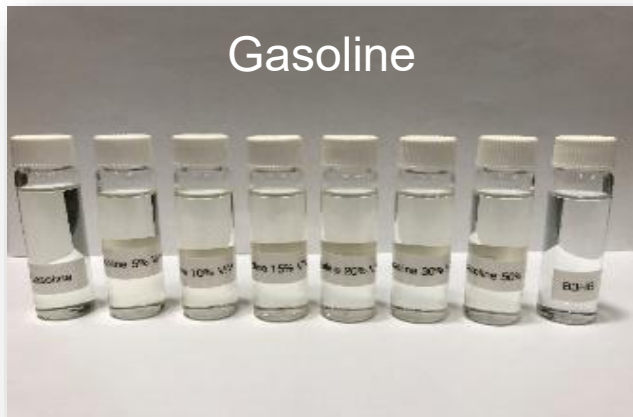


(patent filed PCT/EP2021/085203)

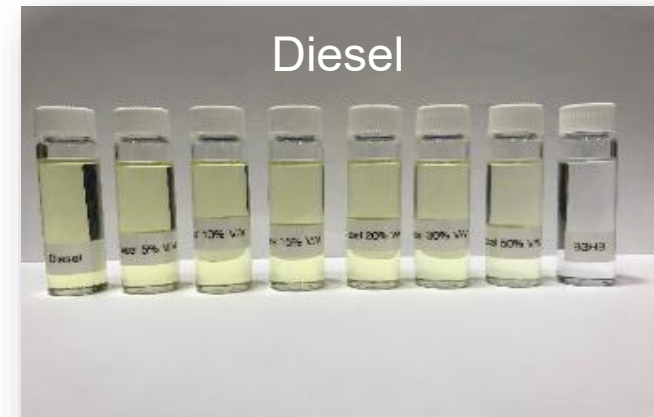
Biofuel Formulations & Engine Tests

Our biofuel *n*-butyl 3-hydroxybutyrate (B3HB) is miscible in any ratio with gasoline and diesel 0, 5, 10, 15, 20, 30, 50 %V/V or can be used pure.

The combustion heat of 20% solution in gasoline is better than the corresponding methyl ester (M3BH) and similar to *n*-butanol.



Fuel	Density (20 °C) [g/mL]	Combustion heat (HHV) [J/g]
M3HB:SP98 20 %V/V	0.79	37'381
<i>n</i> -butanol:SP98 20 %V/V	0.75	40'416
B3HB:SP98 20 %V/V	0.78	38'664
SP98		42'616



Characteristics and performance of different fuels/solvents

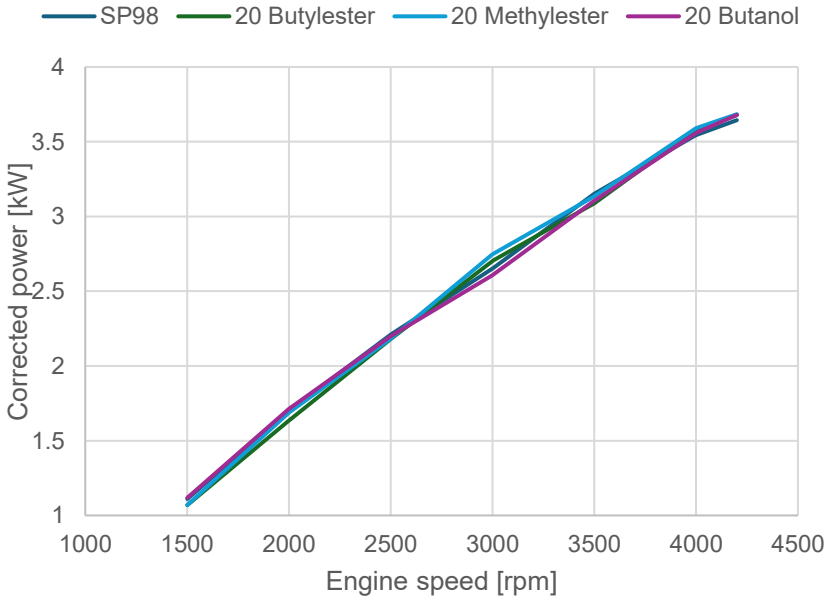
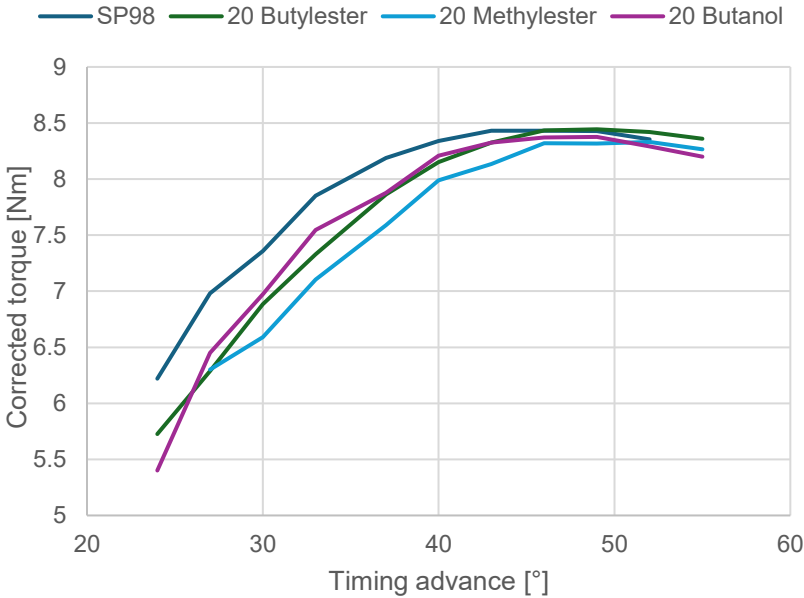
	EtOH	n-BuOH	Gasoline SP98	Diesel	Butan-1,3-diol	B3HB
Chemical Formula	C ₂ H ₆ O	C ₄ H ₁₀ O	-	-	C ₄ H ₁₀ O ₂	C ₈ H ₁₆ O ₃
Oxygen content [%]	34.8	21.6	0	0	35.5	30.0
Freeze point [°C]	-114	-90	-40	-20	<-50	< -60
Boiling point [°C]	78	117	30~205	180~410	204	240
Viscosity [mPa·s] 20°C	1.2	2.6	0.47~0.6	2.5~6.7	96	7
Combustion heat (HHV) [J/g]	26'800	36'100	42'616	42'500	27'700	29'948
Combustion heat (HHV) [J/ml]	21'150	29'240	31'110	35'700	27'980	29'050
Density [kg/m₃] 20°C	789	810	730	840	1010	970

Biofuel Formulations & Engine Tests

Engine smoothly ran on all fuels at almost identical torque (Graph 1) and power (Graph 2). Our biofuel/SP98 had a minimum fuel-air equivalence ratio that was higher than with the other fuel blends, i.e., it had to run slightly richer for the engine to be able to sustain combustion.



Capacity	98 cm ³
Number of cylinders	1 with OHV
Power cycle	4-Stroke
Compression ratio	8.5:1
Max. power (stock, not optimised)	2 kW
Max. torque (stock, not optimised)	4.5 Nm
Max. speed	4200 rpm
Cooling type	Air cooled
Fuel system	Port fuel injection with electronic injection and ignition, naturally aspirated



Take home message

- Large-scale PHA materials deployment needs to be associated with recycling solutions.
- Proposed solution: thermochemical conversion to biofuel
 - Demonstrated with PHB and its conversion to B3HB
 - Production of 5 L, being developed at 100 L.
- B3HB can be used as solvent, biofuel, feedstock, etc.
 - Fully **biobased** approach to biofuel
 - Biodegradability of B3HB is to be evaluated, preliminary results showed promising results
- **Circular bioeconomy** for sustainable transportation based on **existing infrastructure**
 - Positive preliminary LCA Data
 - Scalable technology & Patent filed

