Fermentation of syngas: Scalability for single cell protein (SCP) for feed and food as well as bioplastics (polyhydroxyalkanoates, PHA)

Dr. Maximilian Lackner
CIRCE Biotechnologie GmbH
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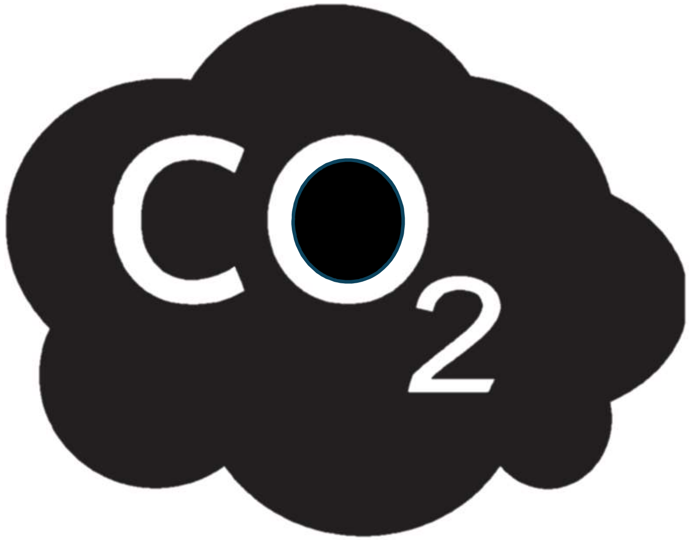
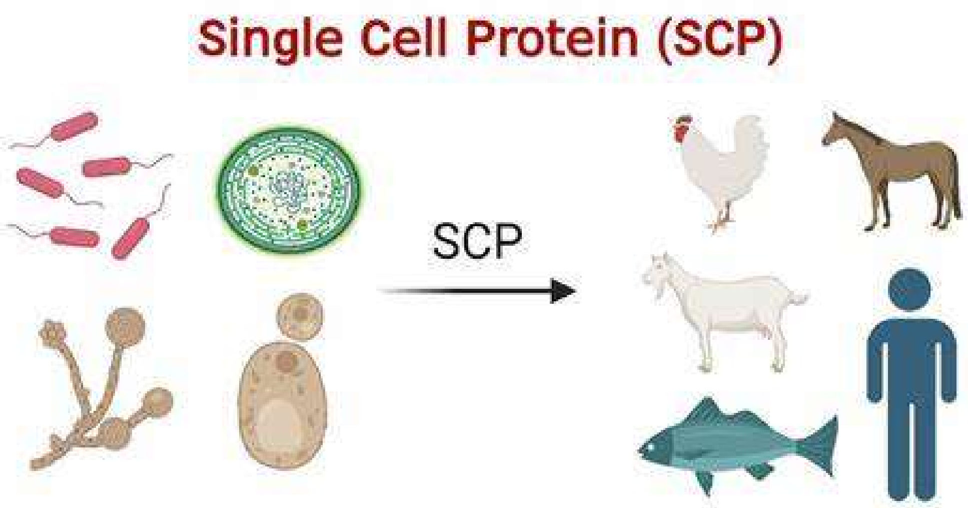
About this talk

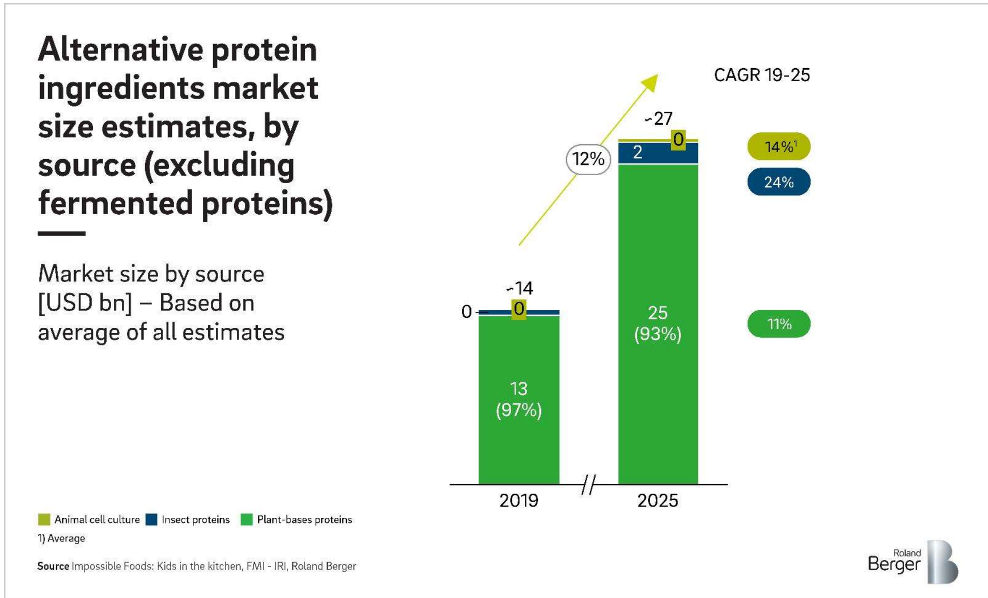
Alternative proteins
Bioplastics



Alternative proteins: Single cell protein (SCP)

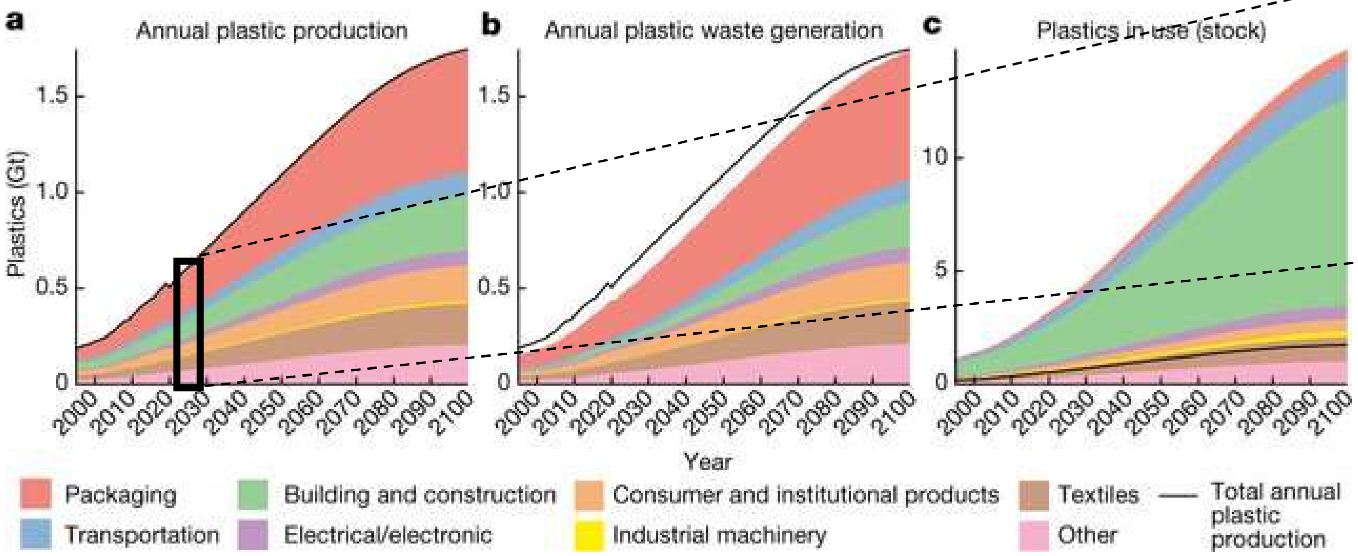


https://microbenotes.com/single-cell-protein/

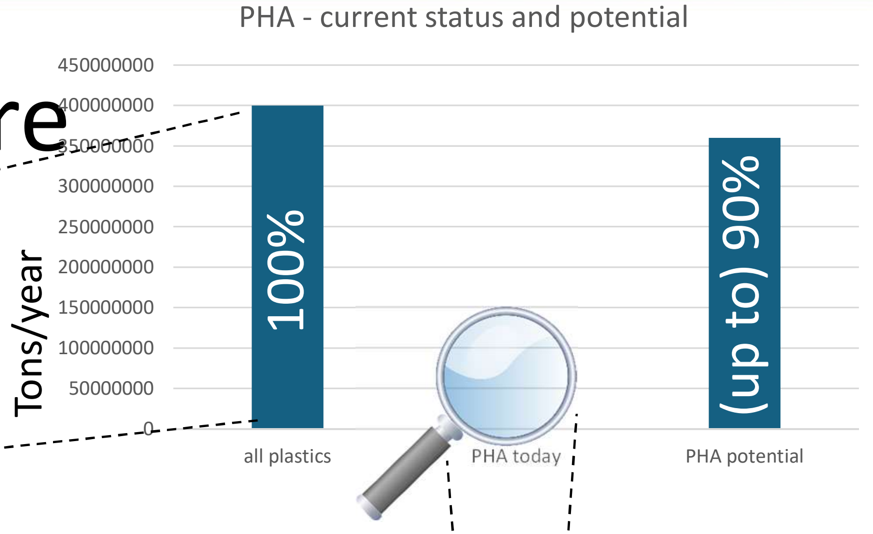


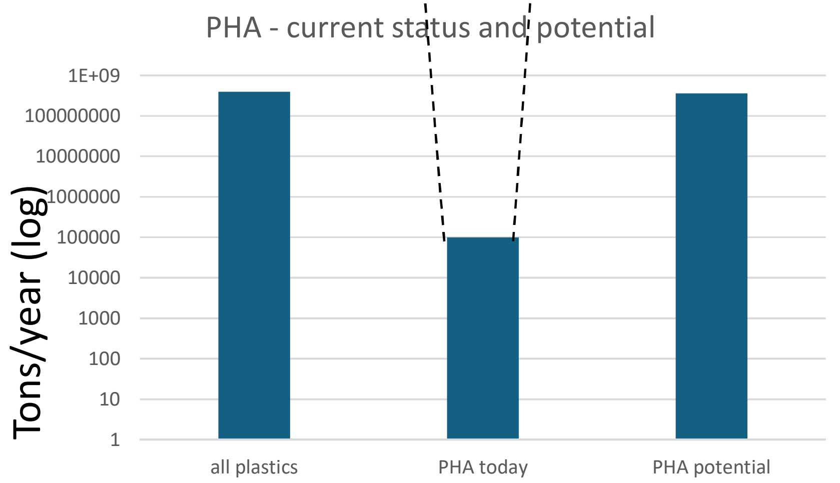
https://www.rolandberger.com/en/Insights/Publications/The-rise-of-alternative-proteins.html

Bioplastics PHA: Today & in future



Plastic futures and their CO_2 emissions
Nature 612(7939):272-276, DOI: 10.1038/s41586-022-05422-5





PHA = polyhydroxyalkanoates
90% potential: natural PHAs function as thermoplastics and building block in thermosets, very versatile.
PHB, PBHV, PHBH and P3HB4HB copolymers, etc.

Compare first generation biofuels

Classic raw material for PHA and SCP (yeast) as well as lab-grown meat is sugar

https://www.britannica.com/technology/biofuel

→Gas fermentation as possible solution

90% replacement of conventional polymers by PHA:

Gas fermentation in general

State-of-the-art:

- Low-cost feedstocks, can be biobased
  - Aerobic process: CH_4 (e.g. biogas)
  - Anaerobic process: CO or H_2 and CO_2 (e.g. biomass gasification)

- Low footprint possible (land use, water, fertilizer, …)
- Decoupling from agricultural primary production feasible
- Challenge: Low solubility of feed gases in water
- Long history, now at the verge of large commercialization

Target products:

- Bacterial single cell protein (SCP) for feed and food
- Biopolymers (polyhydroxybutyrate, PHB, and other PHA)

Remaining problem to be solved:

- Biogas production: CO_2 ↑
- CH_4 fermentation: CO_2 ↑
- Syngas production: CO_2 ↑

Biogas:

Carbohydrates, e.g. cellulose: $C_nH_{n-2}O_{n-1}$ + nH_2O --> 1/2n CH_4 + 1/2n CO_2 (CH_4:CO_2 = 50:50)

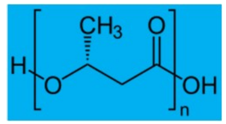
Proteins: $C_{10}H_{20}O_6N_2$ + 3 H_2O --> 5.5 CH_4 + 4.5 CO_2 + 2 NH_3 (CH_4:CO_2 = 55:45)

Fats, vegetable oils: $C_{54}H_{106}O_6$ + 28 H_2O --> 40 CH_4 + 17 CO_2 (CH_4:CO_2 = 70:30)

Biomass gasification:* $C_xH_yO_z$ --> a CO_2 + b H_2O + c CH_4 + d CO + e H_2 + fC_{2+} + tar + char
(CO:H_2 changed through gasification agent & water gas shift reaction CO + H_2O → CO_2 + H_2)

Methane fermentation: 16 CH_4 + 121.6 O_2 + 0.77 NH_3 --> $C_{2.23}H_{3.4}O_{1.25}N_{0.1}$ + 9.68 CO_2 + 31.86 H_2O

PHB



$(C_4H_6O_2)_n$

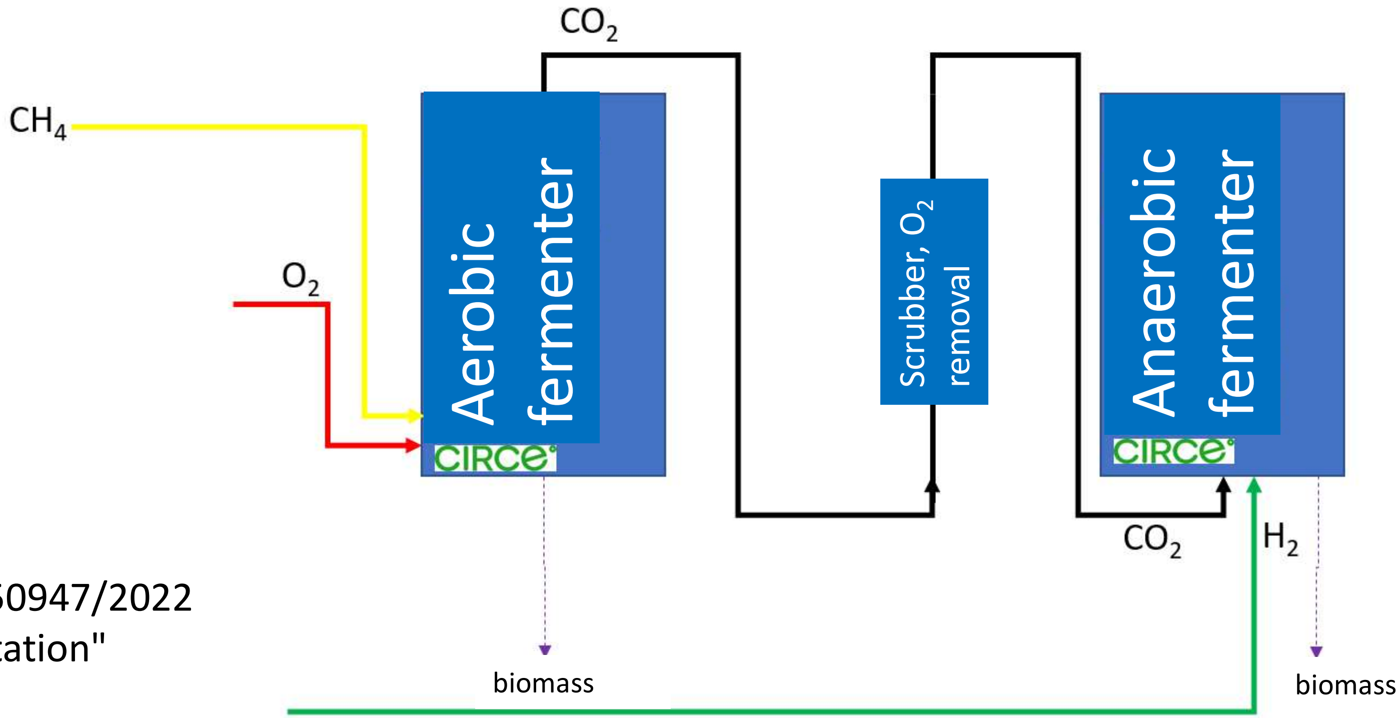
* *"increasing the use of wood from a boreal forest to replace coal in power stations will create a carbon debt that will only be repaid after almost two centuries of regrowth."*
Bjart Holtsmark, Harvesting in boreal forests and the biofuel carbon debt, Climatic Change (2012) 112:415–428, DOI 10.1007/s10584-011-0222-6

Solution: Carbon to be made/kept circular

- Direct use of CO_2? E.g. cyanobacteria for PHB: Very slow growth rates

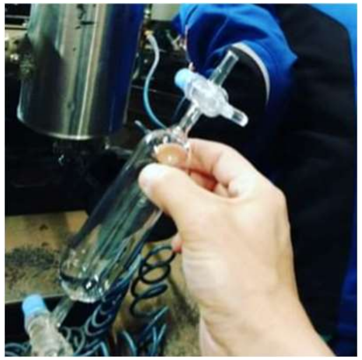
Maximilian Lackner, Donya Kamravamanesh, Margit Krampl, Regina Itzinger, Christian Paulik, Ivan Chodak & Christoph Herwig (2019) Characterization of photosynthetically synthesized poly(3-hydroxybutyrate) using a randomly mutated strain of *Synechocystis* sp. PCC 6714, International Journal of Biobased Plastics, 1:1, 48-59, DOI: 10.1080/24759651.2019.1688603

- **New concept:** Coupling of aerobic and anaerobic fermentation



Patent application A 50947/2022
"Coupled gas fermentation"

Current status



- Strain selection and development
- Fermenter development & scale-up (2 x 30l→2 x 400l → 2 x 5000l)

Reactor	Continuously stirred tank reactor (CSTR)	forced-liquid vertical loop bioreactor (VTLB)	forced-liquid horizontal tubular loop bioreactor (HTLB)	Airlift (AL) fermenter	Bubble column (BC) fermenter
Methane conversion	medium	high	high	high	high
Energy efficiency	Lowest	high	highest	medium	medium
Cooling	Difficult at large scale	best	best	good	good
$k_L a$ value	0.0056 s^{-1}	0.034 s^{-1}	0.037 s^{-1}	0.0482 s^{-1}	0.028 s^{-1}
Productivity	0.14 g/(L·h)	1.0 g/(L·h)	0.786 g/(L·h)	0.15 g/(L·h)	0.18 g/(L·h)

Parya Safaeian, Fatemeh Yazdian, Kianoush Khosravi-Darani, Hamid Rashedi, Maximilian Lackner, P3HB from CH_4 using methanotrophs: Aspects of bioreactor, fermentation process and modelling for cost-effective biopolymer production, Frontiers in Bioengineering and Biotechnology, Volume 11 – 2023, https://doi.org/10.3389/fbioe.2023.1137749

Conclusions

- Bacterial single cell protein (SCP) attractive for feed and food
- PHB (and its copolymers) attractive to replace fossil and non-degradable plastics
- Coupled process can achieve CO_2-neutral gas fermentation.
- Maximum growth rates of 3.75 g/(l*h) were measured. Contents of 51 to 72% of crude protein and max. 78% of PHB were found (dry cell mass).
- The mass balance shows that by coupling the aerobic and the anaerobic fermenters, all carbon in the feedstock can be converted to product.

Thank you for your attention!

m.lackner@circe.at