Clean Production of Bioplastic and Bio-oil from Solar Energy and Carbon Dioxide

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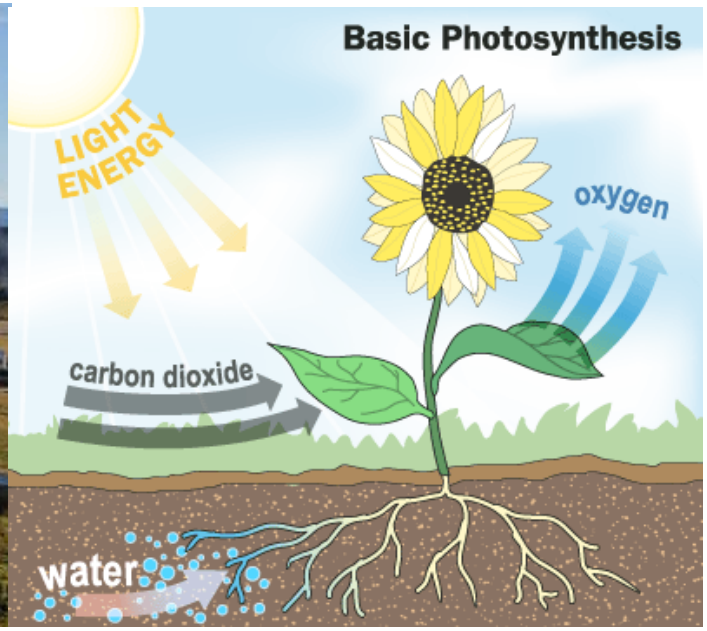
CO_2 Emission and Fixation

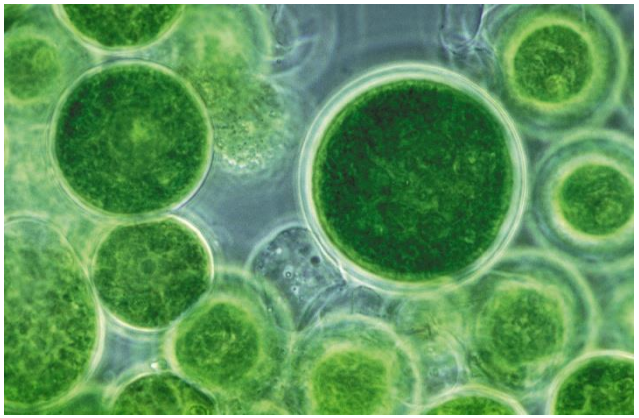


$$CO_2 + H_2O + h\nu \rightleftharpoons CH_2O + O_2$$

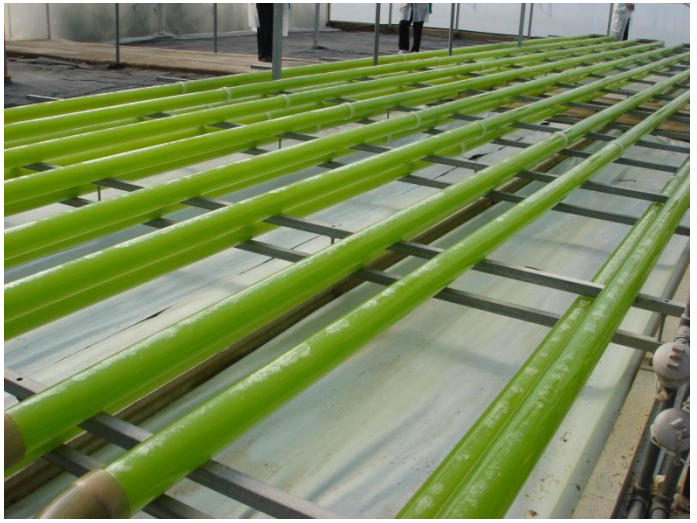
Conventional photosynthesis:

- ❑Theoretical energy efficiency 3-4%,
- ❑ Real efficiency of energy crop (switch glass) <1%
- ❑ Not suitable for industrial solar and CO_2 capture

Microalgae Systems



Individual cells

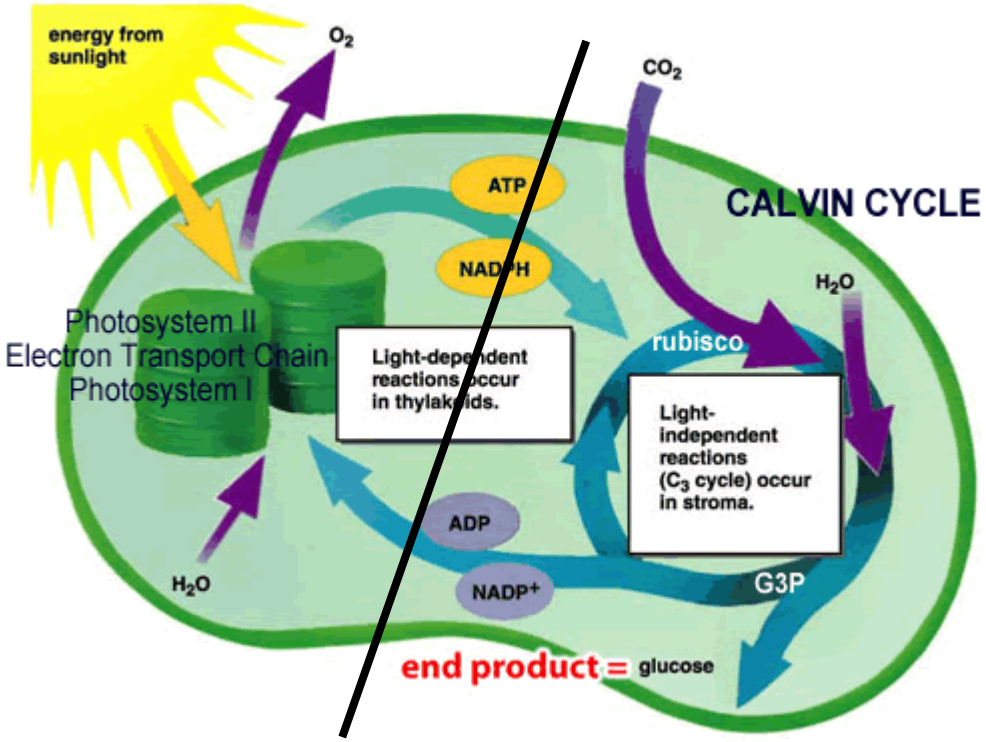


Photobioreactor system

Open pond system

- Surface/volume ratio
- Mixing, cooling, CO_2 sparge
- High capital investment
- Low cell density (< 4 g/L)
- Slow cell growth (double time 34 hours)
- Facility Idle in darkness

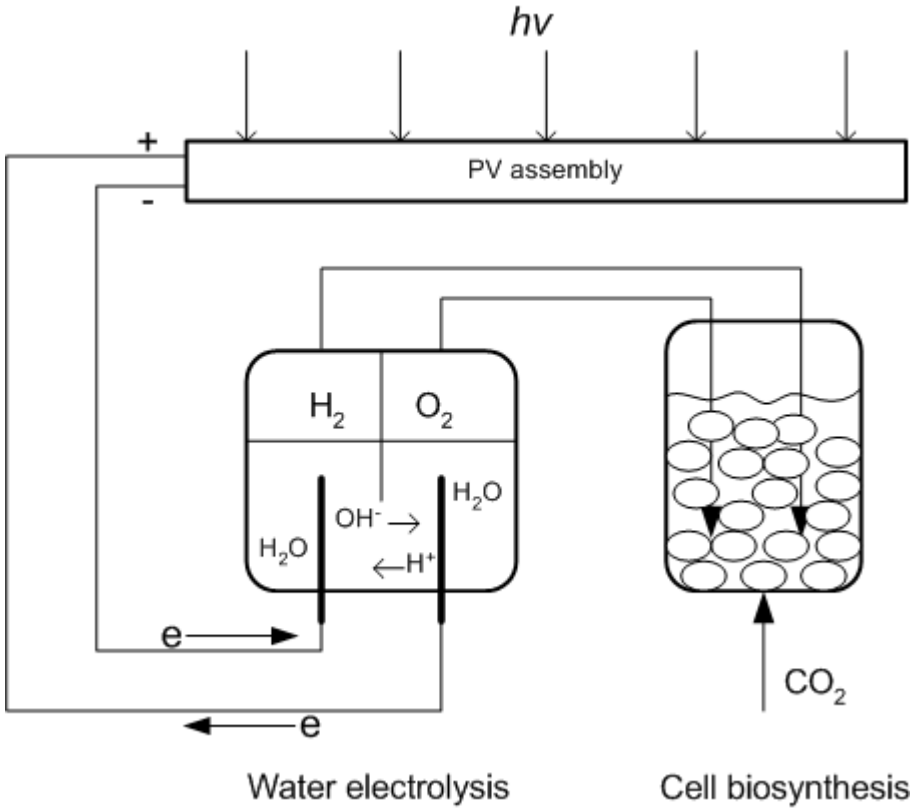
Light Capture Decoupled from CO_2 fixation



Solar energy capture decoupled from CO_2 fixation:

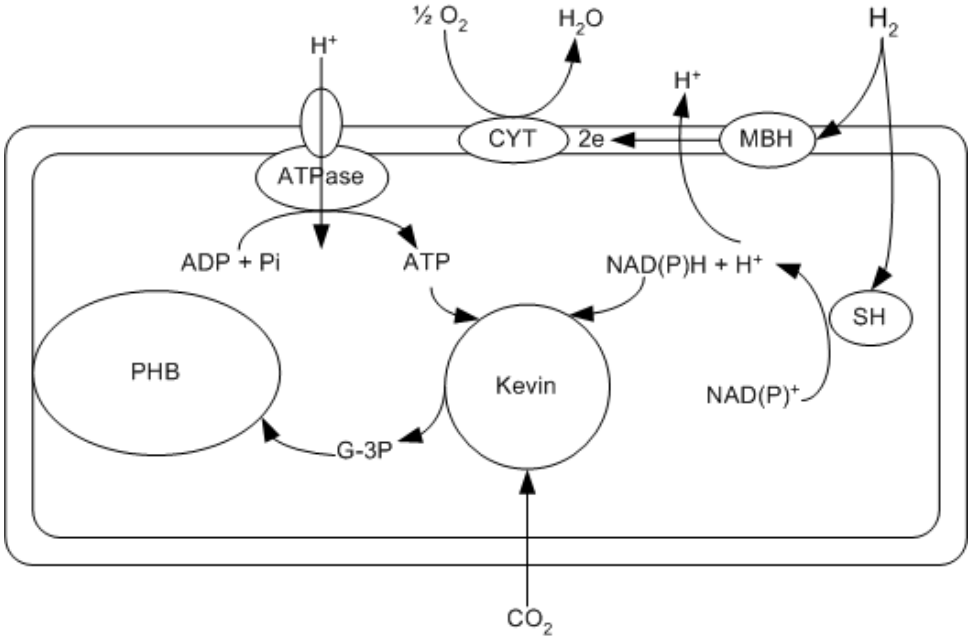
1. **Solar energy → electricity + H_2O → H_2 + ½ O_2 (energy storage)**
2. **$2H_2 + CO_2$ → $CH_2O + H_2O$ (autotrophic CO_2 fixation)**

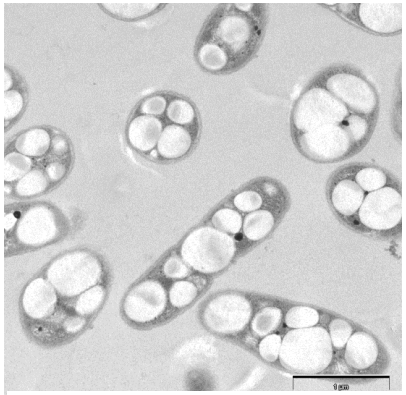
Artificial Photosynthetic System



$$CO_2 + H_2O + hv \longrightarrow CH_2O \text{ (biomass)}$$

CO_2 Fixation by Lithoautotrophic Bacterium





$$HO\text{–}[OCHCH_2C]_n\text{–}OH \quad (CH_3 \text{ on CH}, O \text{ on C})$$

(n=500-10,000)

Polyhydroxybutyrate (40-60 wt%)

Hydrogen used by cells for two purposes:

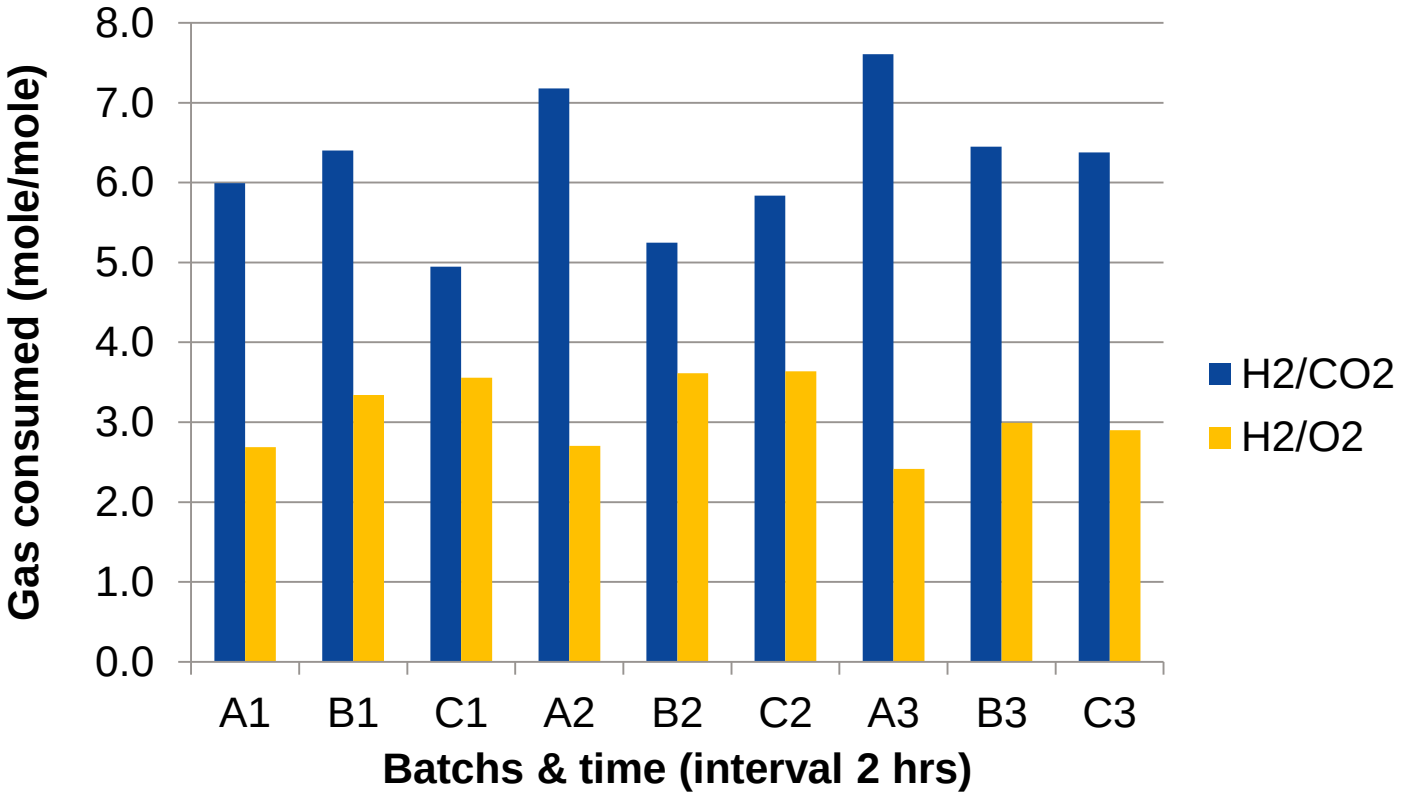
- ❑ H_2 used to reduce CO_2

$CO_2 + 2H_2 \rightarrow CH_2O + H_2O$ (H_2/CO_2 = 2 or more)

- ❑ H_2 reacts with O_2 to release energy for ATP generation: ATP/H_2 = 1 (?)

H_2 Consumed for CO_2 Fixation

$CO_2 + 2H_2 \rightarrow CH_2O + H_2O$ ($H_2/CO_2 > 2$)
$2H_2 + O_2 \rightarrow H_2O$ (ATP)



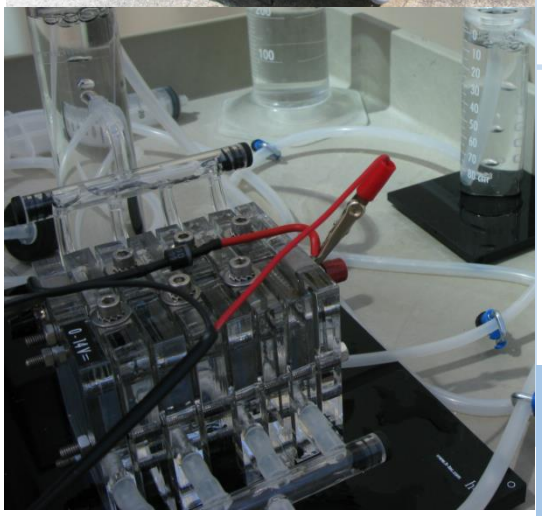
Energy Efficiency of CO_2 Fixation

H_2/CO_2 (mole/mole)	8	5	4
Hydrogen energy used (kJ)	2286	1429	1143
Energy in CH_2O (kJ)	467	467	467
Energy efficiency (%)	20	33	41
H_2/CO_2 for NADH	2	2	2
ATP/H_2	~0.5	~1	~1.5

In the Calvin cycle:

$CO_2 + 2(NADH + H^+) + 3ATP \rightarrow CH_2O + H_2O + 2NAD^+ + 3ADP + Pi$

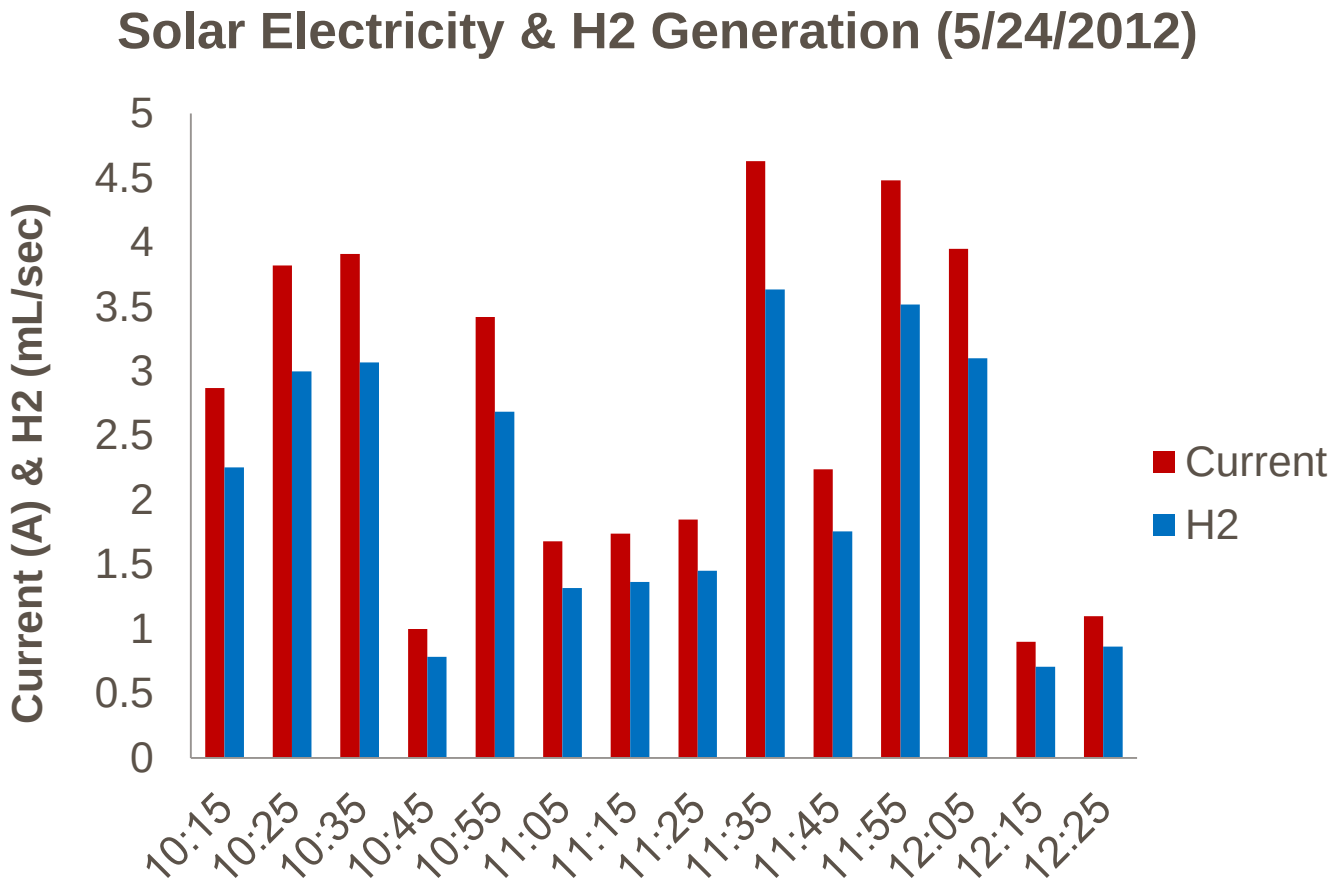
System Energy Efficiency



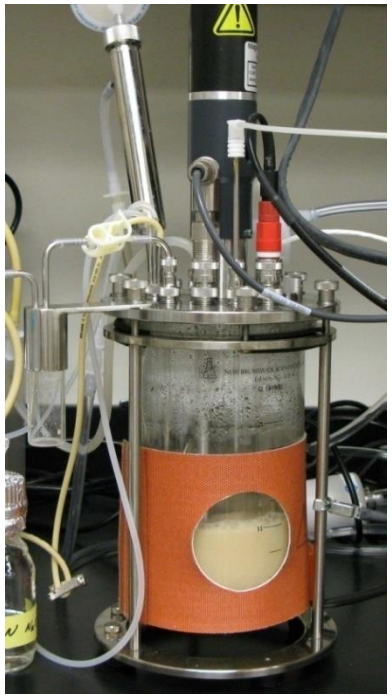
Solar electricity 17%	• Affordable commercial PV assembly • Potential MOVPE efficiency 30-40%
Water electrolysis 83%	• Industrial alkaline electrolyzer 80%
CO_2 fixation 20-33%	• H_2 for reducing agent H_2/NADPH = 1 • H_2 for energy ATP/H_2 = 0.5-1

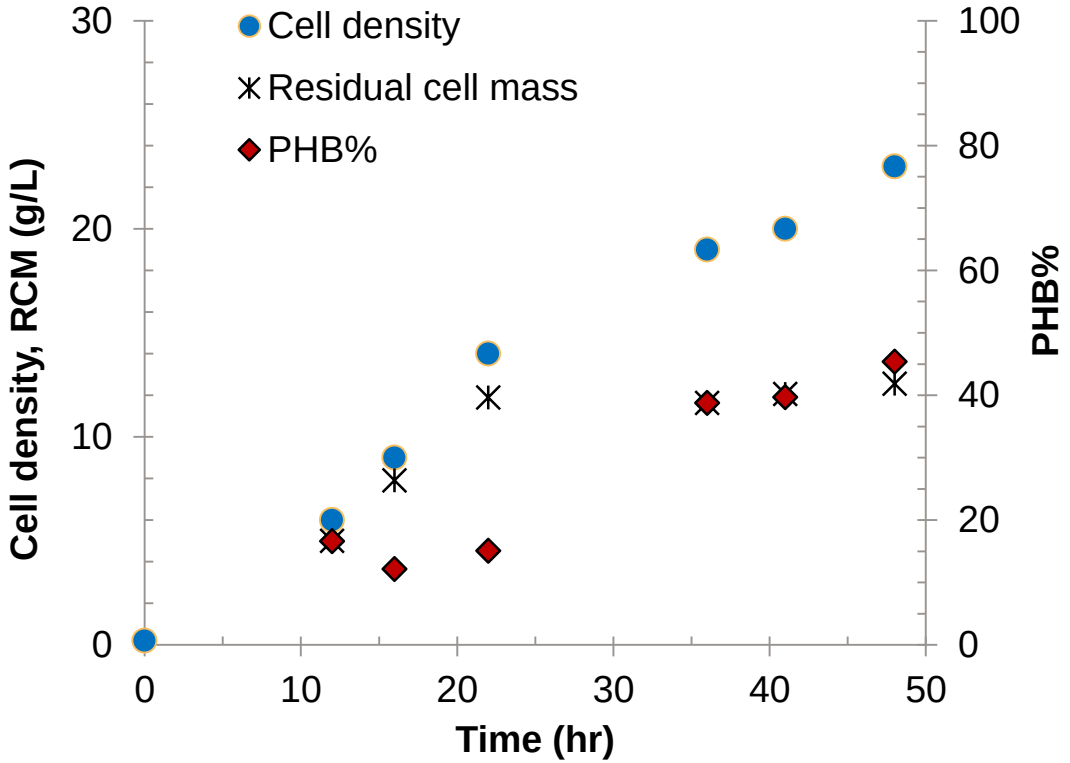
Artificial system's solar energy efficiency of 2.8 – 4.7%

H_2 Generation under Intermittent Solar Radiation



Fast CO_2 Conversion into Biomass

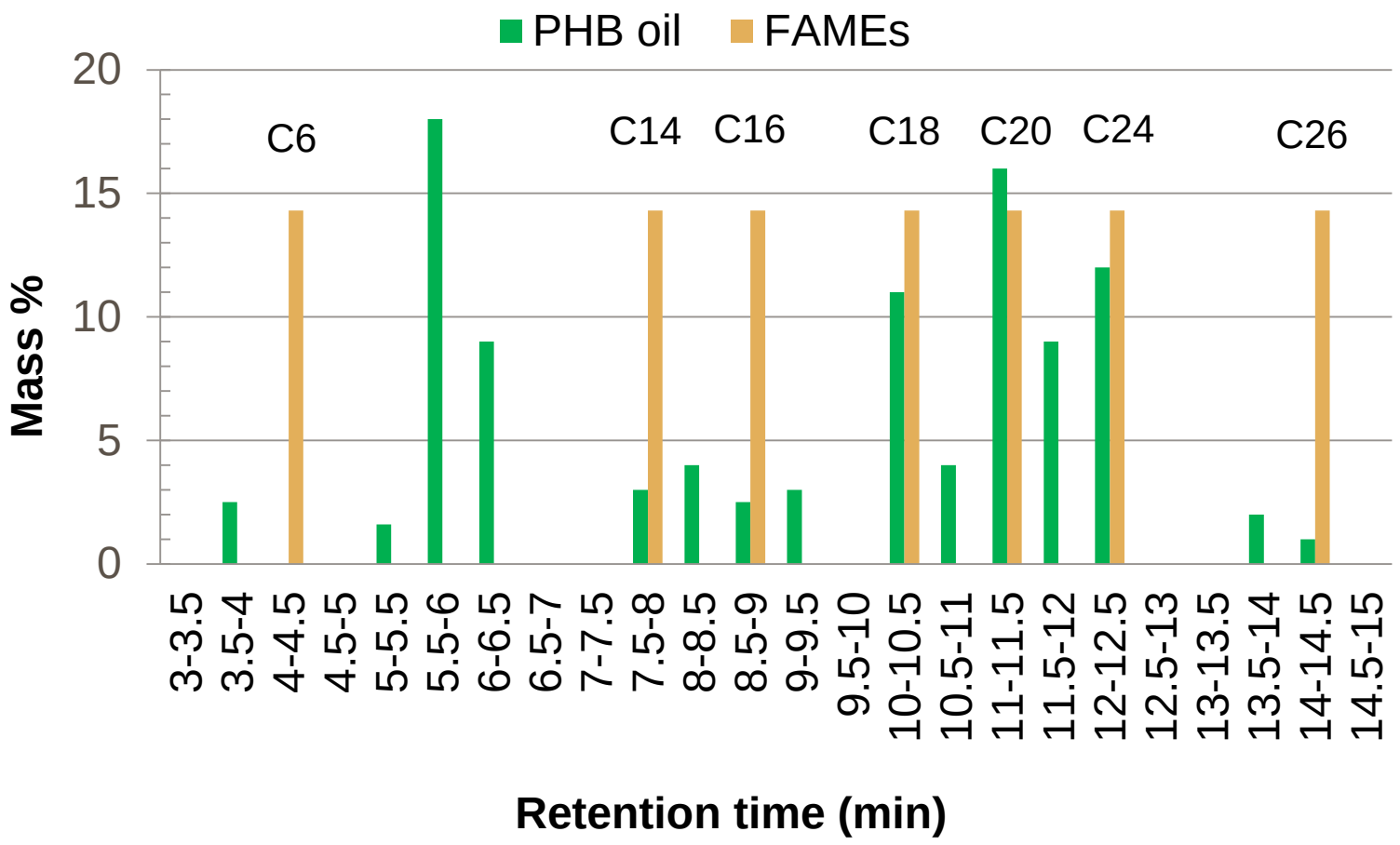




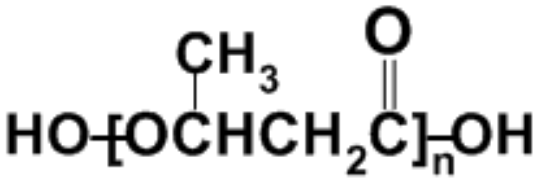
- Double cell mass in 8 hours
- High cell density (23 g/L), compared to < 1-2 g/L of microalgae
- 45-50% of PHB, a polyester of high energy content (50% more than glucose)

Bioplastic of 100% CO_2 Carbon

Bio-oil from PHB Methanolysis



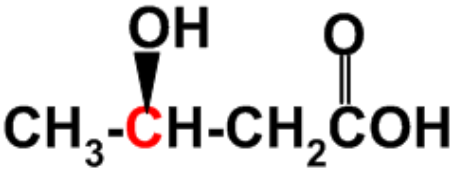
Monomeric Products Derived from PHB



(n=500-10,000)

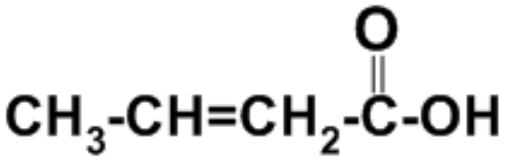
Poly[(R)-3-hydroxybutyrate)]

Hydrolysis



R-3-hydrobutyric acid

Dehydration



Crotonic acid

Conclusion & Acknowledgement

Conclusions:

- CO_2 fixation with sunlight and water on 24/7 mode for power plants, cement plants and oil refineries.
- The measured energy efficiency of biological CO_2 conversion is 20-33% based on solar H_2
- The overall efficiency from solar to biomass energy is 2.8-4.7%
- Conversion of CO_2 to bio-based plastics, oil, and chemicals.

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