Direct Conversion of CO_2 into Biopolyester with Solar Energy and Water

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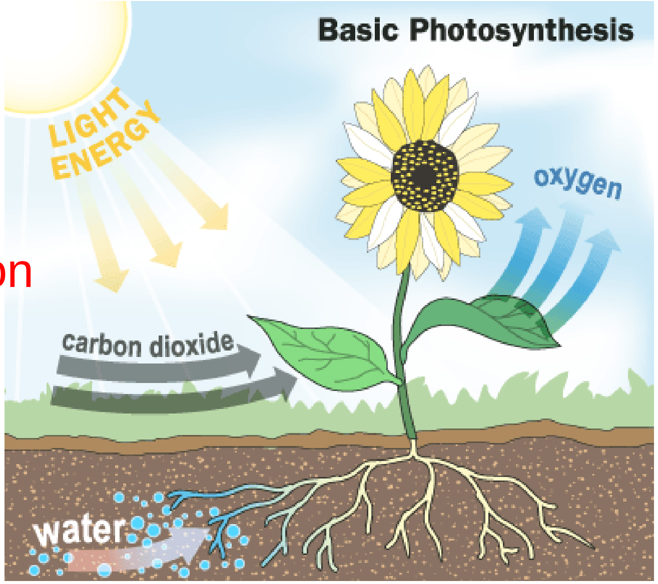
Indirect Biopolyester Production From CO_2

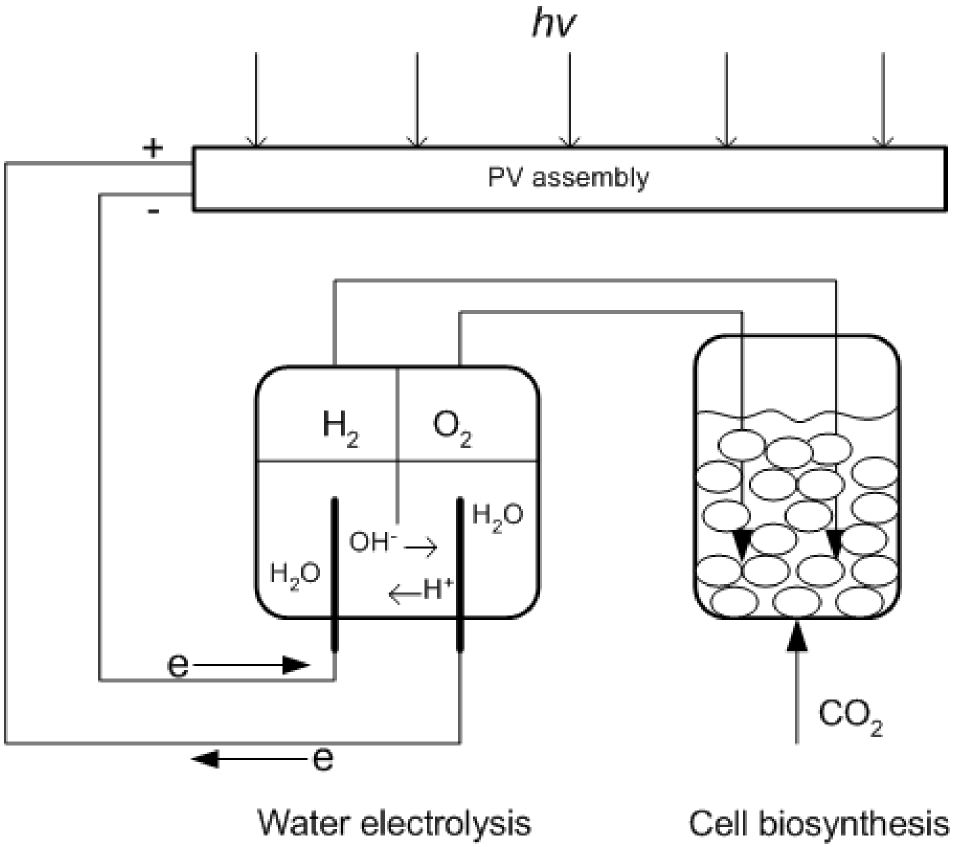
Annual solar irradiation
5.4 GJ/m^2



$CO_2 + H_2O + hv \rightarrow CH_2O + O_2$

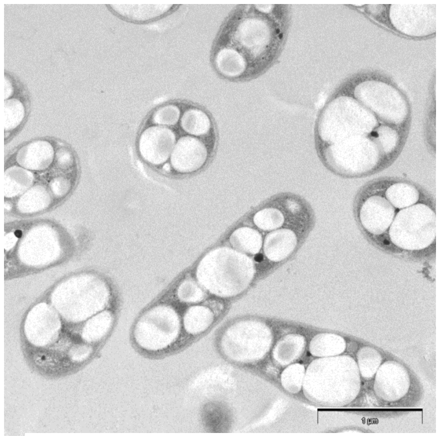
- ❑ Vegetable oil or starch from photosynthesis of CO_2, H_2O and sunlight
- ❑ Biopolyester formed from the fermentable feedstocks
- ❑ Theoretical photosynthesis efficiency of high plants 4-5%,
- ❑ Real efficiency of fast growing crops (e.g. switchgrass) <1%
- ❑ Competition of food, feed, and bio-based products for arable land

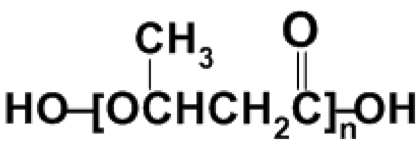
Artificial Photosynthetic System



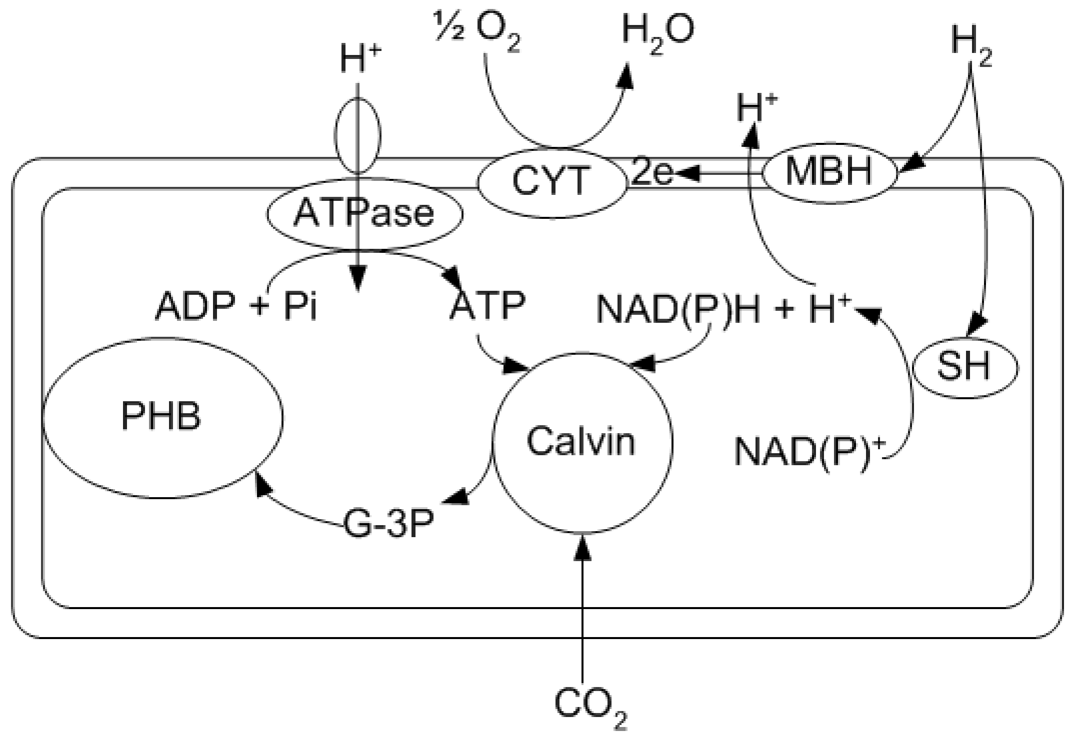
$$CO_2 + H_2O + hv \longrightarrow CH_2O \text{ (biomass)}$$

CO_2 Fixation by a Lithoautotrophic Bacterium





(n=500-10,000)



Granules of polyhydroxybutyrate (40-60 wt%) accumulated in bacterial cells as carbon and energy storage material

Energy Efficiency of CO_2 Fixation

Hydrogen used by cells for two purposes:

- ❑ H_2 used to produce NADH for reduction of CO_2

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

- ❑ H_2 reaction with O_2 to release energy for ATP generation

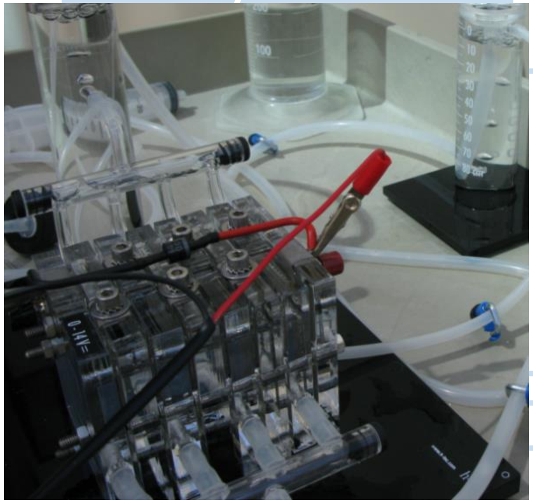
$$H_2 + ½\, O_2 \rightarrow H_2O$$

H_2/CO_2 (mole/mole)	16.3	5.9	3.3	2.5
O_2 (mole %)	31.4	23.3	10.7	6.3
Hydrogen energy used (kJ)	4658	1686	943	715
Energy efficiency (%)	10 [(a)]	27.7	49.5	65.3 [(b)]

(a) No biomass synthesis
(b) Very slow CO_2 assimilation and biosynthesis

Ref. Yu, J. *et al. Internal Journal of Hydrogen Energy*, 38 (2013) 8683-90,

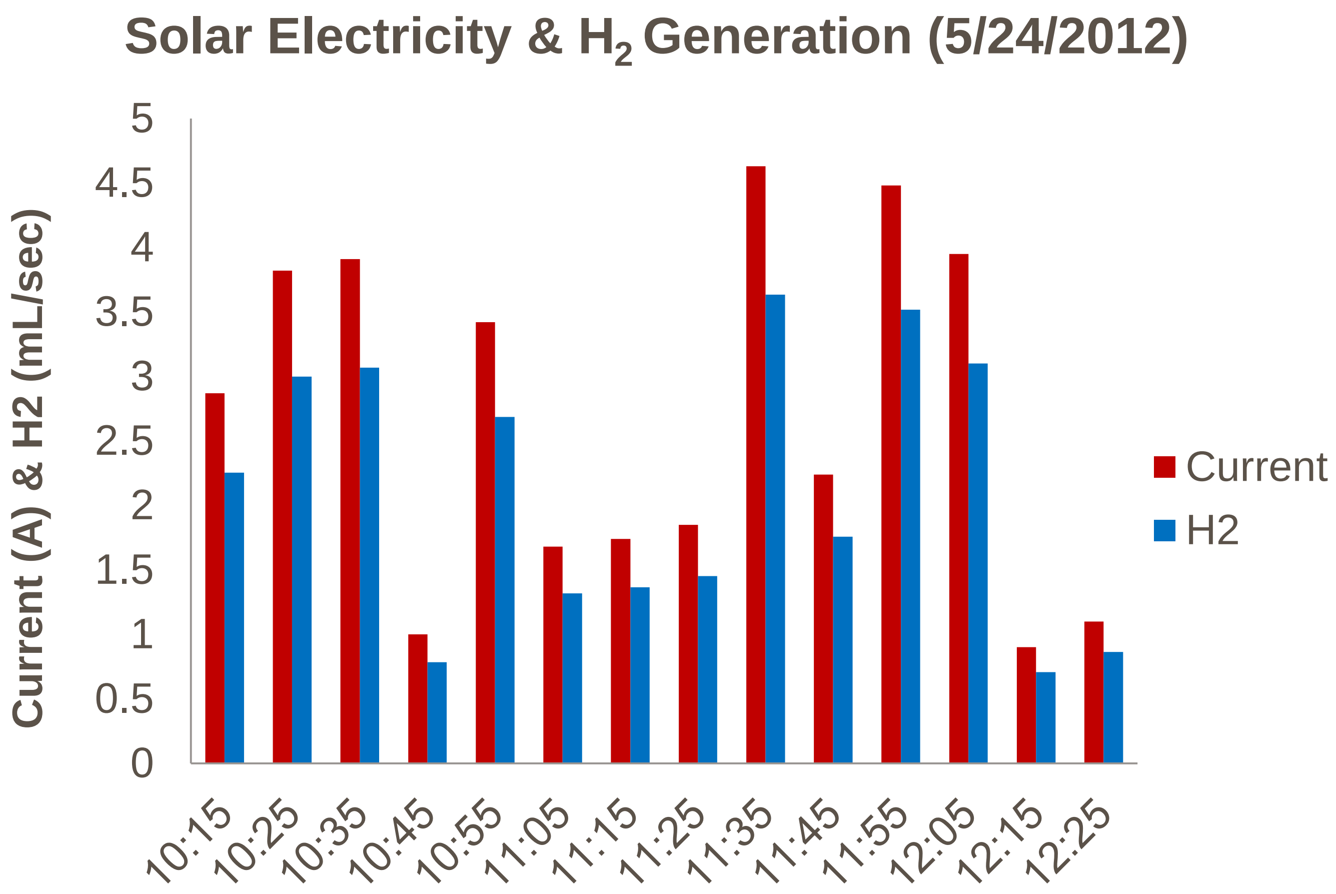
System Energy Efficiency



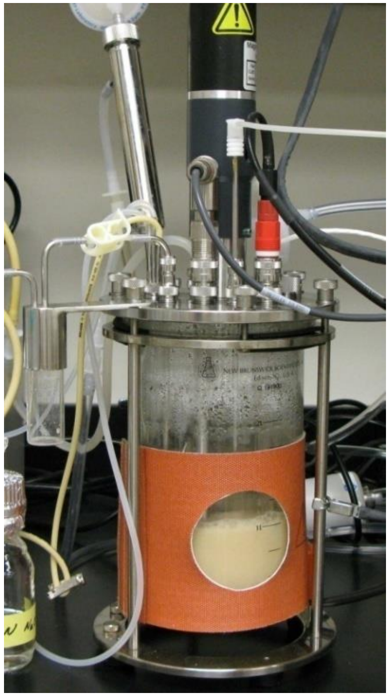
Solar electricity 15%	• Affordable commercial PV assembly • High efficiency 20-30%
Water electrolysis 80%	• Industrial electrolyzer 60-80%
CO_2 fixation 28-50%	• Low efficiency for high rate

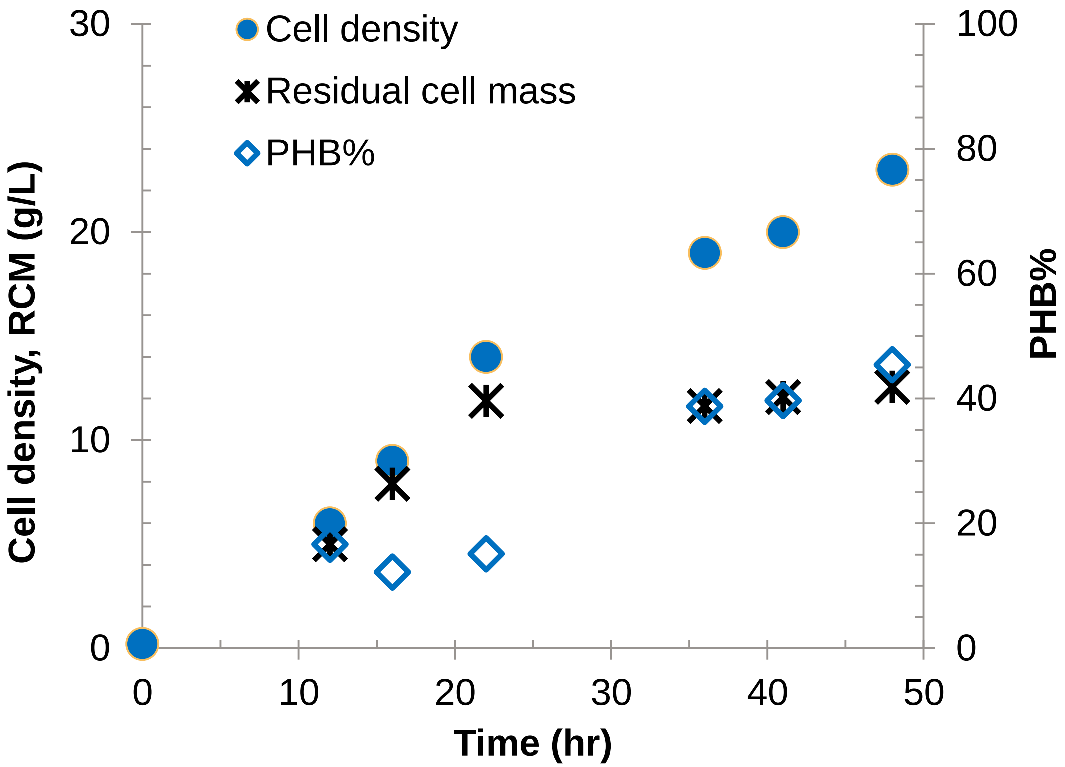
A laboratory artificial system's solar energy efficiency 3.4 – 6%

H_2 Generation under Intermittent Solar Radiation



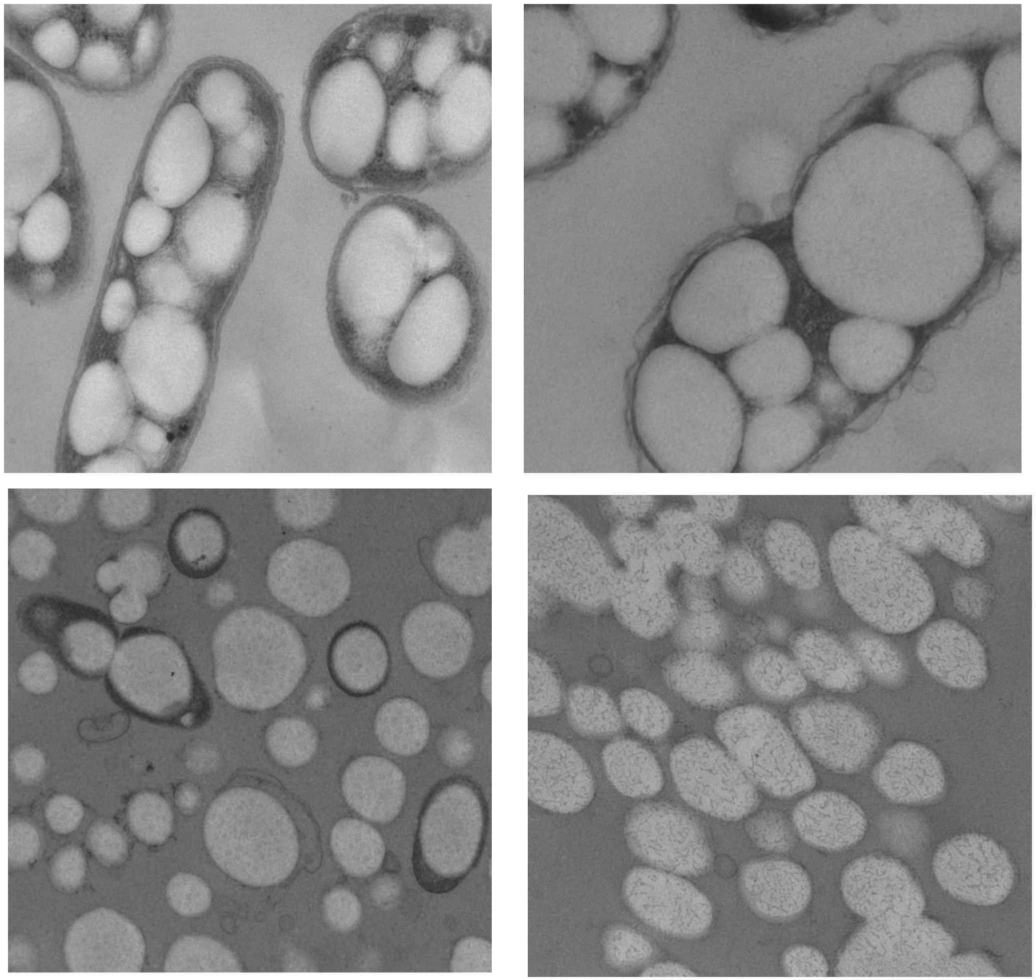
Fast CO_2 Conversion into Biomass



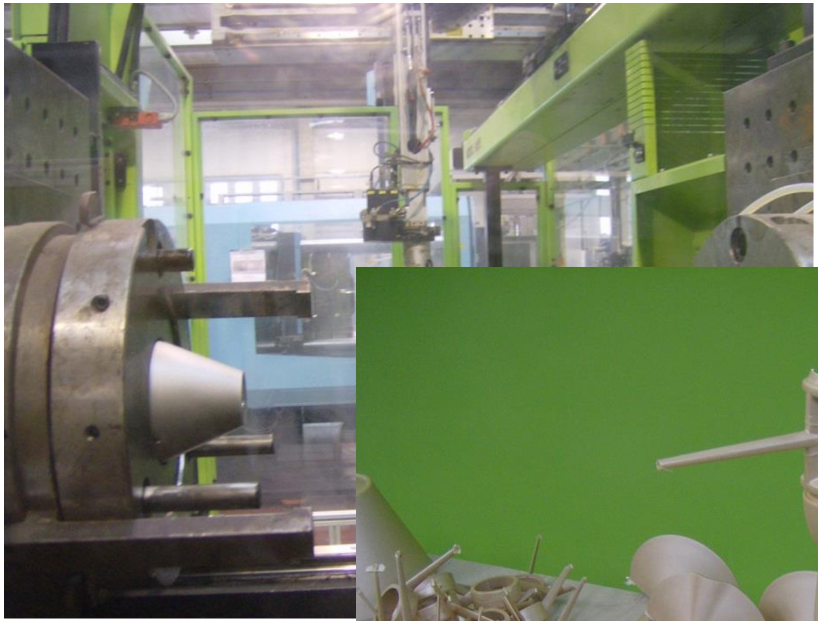


- ❑ Cell mass doubled in 8 hours
- ❑ High cell density of 23 g/L
- ❑ 45-50% of PHB, a biopolyester material

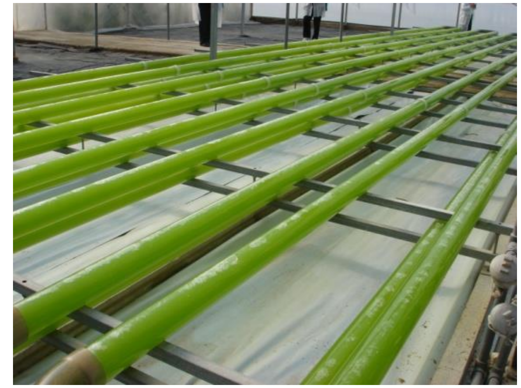
Biopolymer Recovered from Living Cells



Bioplastic of 100% CO_2 Carbon



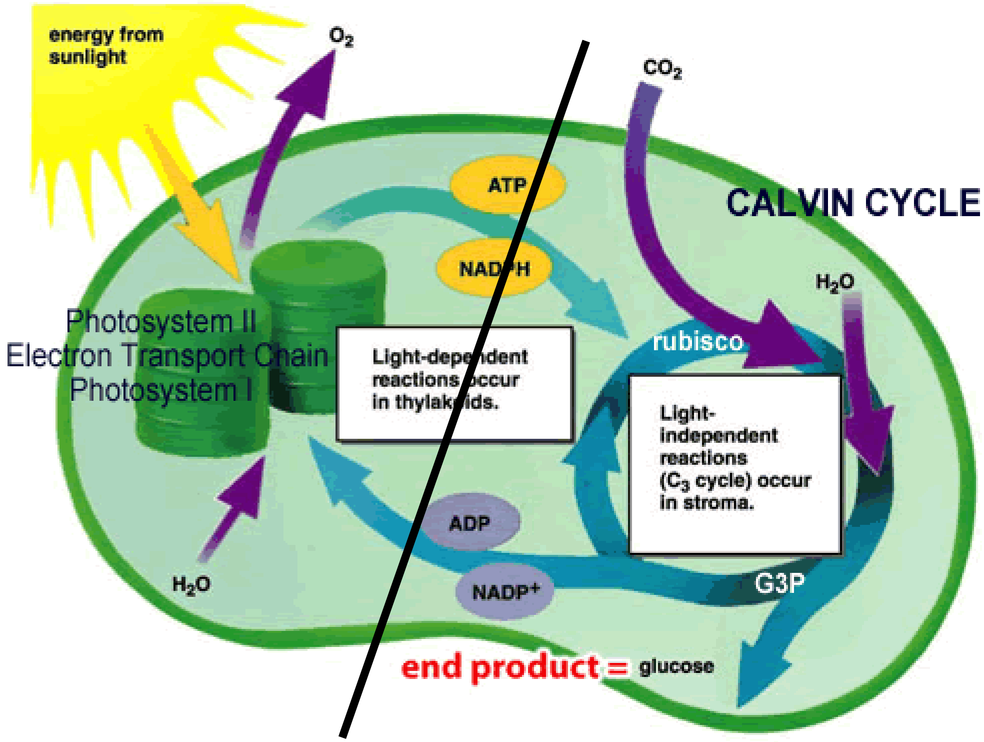
Artificial Photosynthesis vs Cyanobacterium



Photosynthesis	Artificial	Natural [a]
Species	*Ralstonia eutropha*	*Arthrospira platensis*
Solar energy efficiency (%)	3.4-6	2.5
Cell density (g/L)	23	3.6
Cell double time (hrs)	8	48
PHB or carbohydrate (wt%)	45	19.2
Productivity (g/L.hr)	0.25	0.01
Scale up cost	Low	High

(a). Tredici, M.R. & Zittelli, G.C. *Biotech. Bioeng*. 57(**1998**) 187-197

Why is the Artificial System More Efficient?



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)**

Conclusions

- Biopolyester can be directly produced from CO_2, solar energy and water via an artificial photosynthetic system
- The overall solar energy efficiency is 3-6%
- The purified biopolyester can be processed like petrochemical plastic.
- The artificial photosynthesis has much higher energy efficiency and productivity than natural photosynthesis

Acknowledgement

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Thank You !!!