COST TD1102
PHOTOTECH: BIOSENSORS & BIOCHIPS

TRAINING SCHOOL ON "PHOTOTECH FOR BIOSENSORS AND ENERGY", 21-25 OCTOBER, AMARILIA HOTEL, VOULIAGMENI, ATHENS, GREECE 2013

Screening of electricity producing profile of various photosynthetic microorganisms

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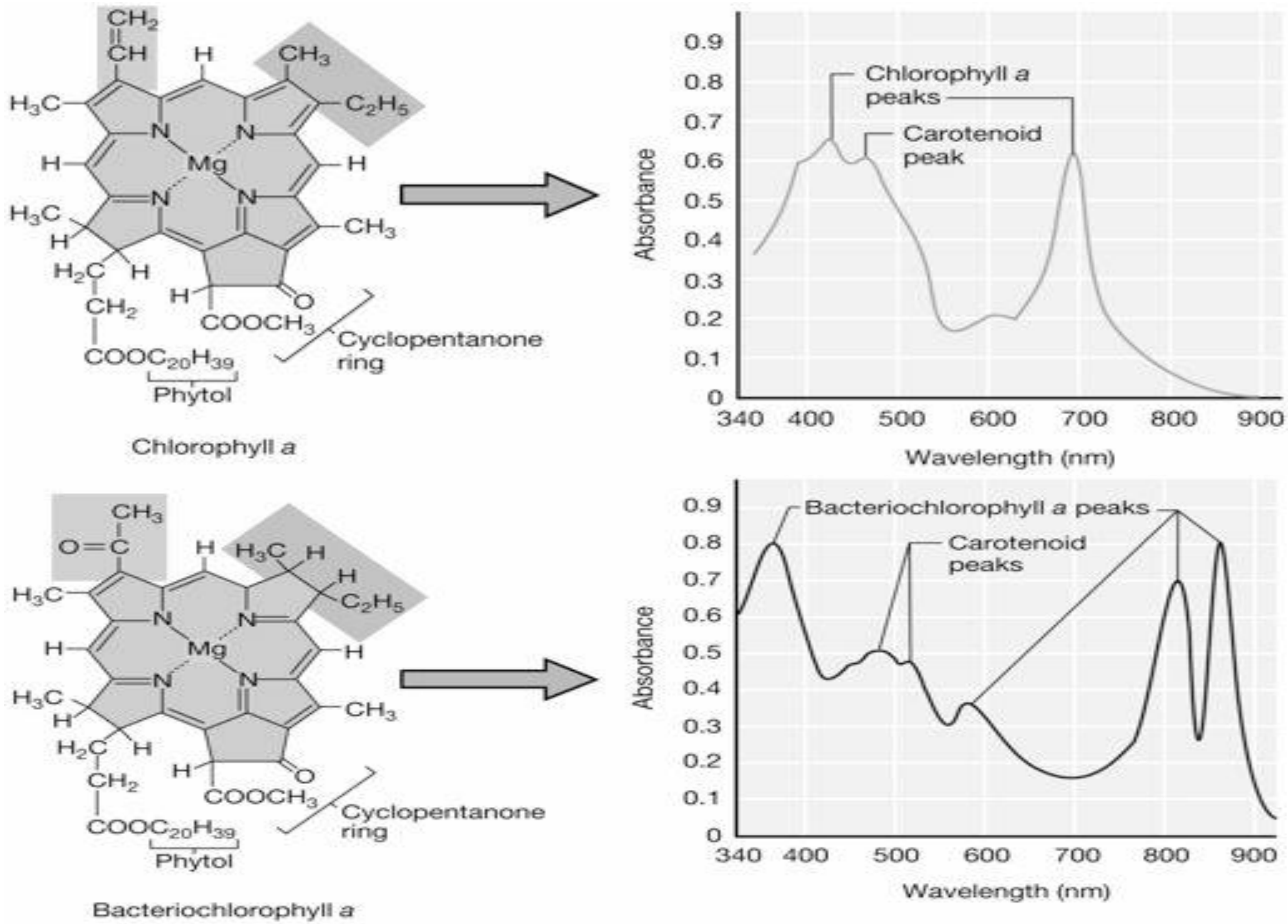
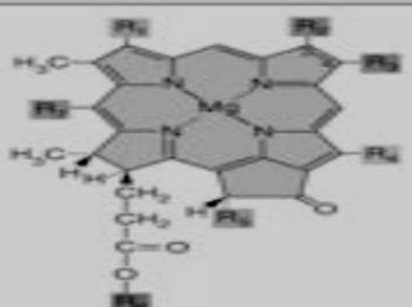
- Plants use a substance called chlorophyll to absorb the sun's rays
- Bacteria contain bacteriochlorophyll, which allows them to also photosynthesize.

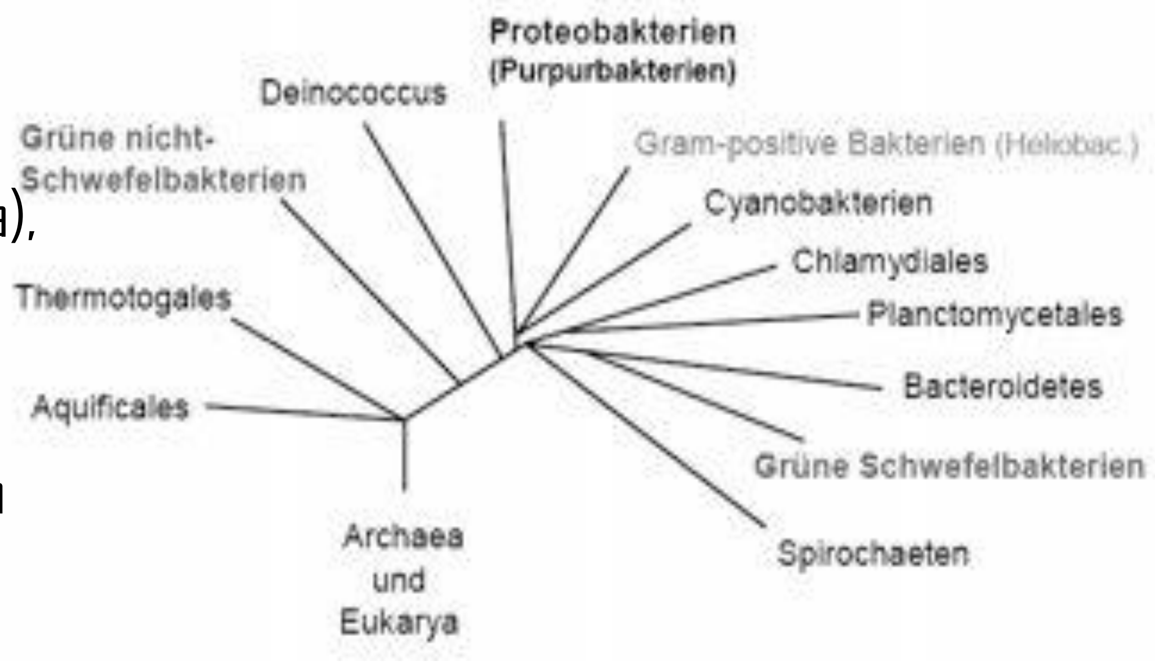

Chlorophyll a
Cyclopentanone ring
Phytol
Chlorophyll a peaks
Carotenoid peak
Absorbance
Wavelength (nm)
Bacteriochlorophyll a
Bacteriochlorophyll a peaks
Carotenoid peaks

Pigment	R_1	R_2	R_3	R_4	R_5	R_6	R_7	maxima (nm) *In vivo*	maxima (nm) Extract (methanol)
Bacterio-chlorophyll *a* (purple bacteria)	$-C(=O)-CH_3$	$-CH_3$[b]	$-CH_2-CH_3$	$-CH_3$	$-C(=O)-O-CH_3$	P/Gg[a]	$-H$	805 830–890	771
Bacterio-chlorophyll *b* (purple bacteria)	$-C(=O)-CH_3$	$-CH_3$[c]	$=C(H)-CH_3$	$-CH_3$	$-C(=O)-O-CH_3$	P	$-H$	835–850 1020–1040	794
Bacterio-chlorophyll *c* (green sulfur bacteria)	$-C(H)(OH)-CH_3$	$-CH_3$	$-C_2H_5$ $-C_3H_7$[d] $-C_4H_9$	$-C_2H_5$ $-CH_3$	$-H$	F	$-CH_3$	745–755	660–669
Bacterio-chlorophyll c_s (green nonsulfur bacteria)	$-C(H)(OH)-CH_3$	$-CH_3$	$-C_2H_5$	$-CH_3$	$-H$	S	$-CH_3$	740	667
Bacterio-chlorophyll *d* (green sulfur bacteria)	$-C(H)(OH)-CH_3$	$-CH_3$	$-C_2H_5$ $-C_3H_7$ $-C_4H_9$	$-C_2H_5$ $-CH_3$	$-H$	F	$-H$	705–740	654
Bacterio-chlorophyll *e* (green sulfur bacteria)	$-C(H)(OH)-CH_3$	$-C(=O)-H$	$-C_2H_5$ $-C_3H_7$ $-C_4H_9$	$-C_2H_5$	$-H$	F	$-CH_3$	719–726	646
Bacterio-chlorophyll *g* (heliobacteria)	$-C(H)=CH_2$	$-CH_3$[b]	$-C_2H_5$	$-CH_3$	$-C(=O)-O-CH_3$	F	$-H$	670, 788	765

[a] P, Phytyl ester ($C_{20}H_{39}O-$); F, farnesyl ester ($C_{15}H_{25}O-$); Gg, geranylgeraniol ester ($C_{10}H_{17}O-$); S, stearyl alcohol ($C_{18}H_{37}O-$).
[b] No double bond between C_3 and C_4; additional H atoms are in positions C_3 and C_4.
[c] No double bond between C_3 and C_4; an additional H atom is in position C_3.
[d] Bacteriochlorophylls *c*, *d*, and *e* consist of isomeric mixtures with the different substituents on R_3 as shown.



- cyanobacteria,
- proteobacteria (purple bacteria),
- green nonsulfur bacteria,
- green sulfur bacteria
- the Gram-positive heliobacteria



Phylogenetic affiliation of phototrophic bacteria

- The purple bacteria and green nonsulfur bacteria synthesize a nonoxygen-evolving type II photosystem;
- the green sulfur bacteria

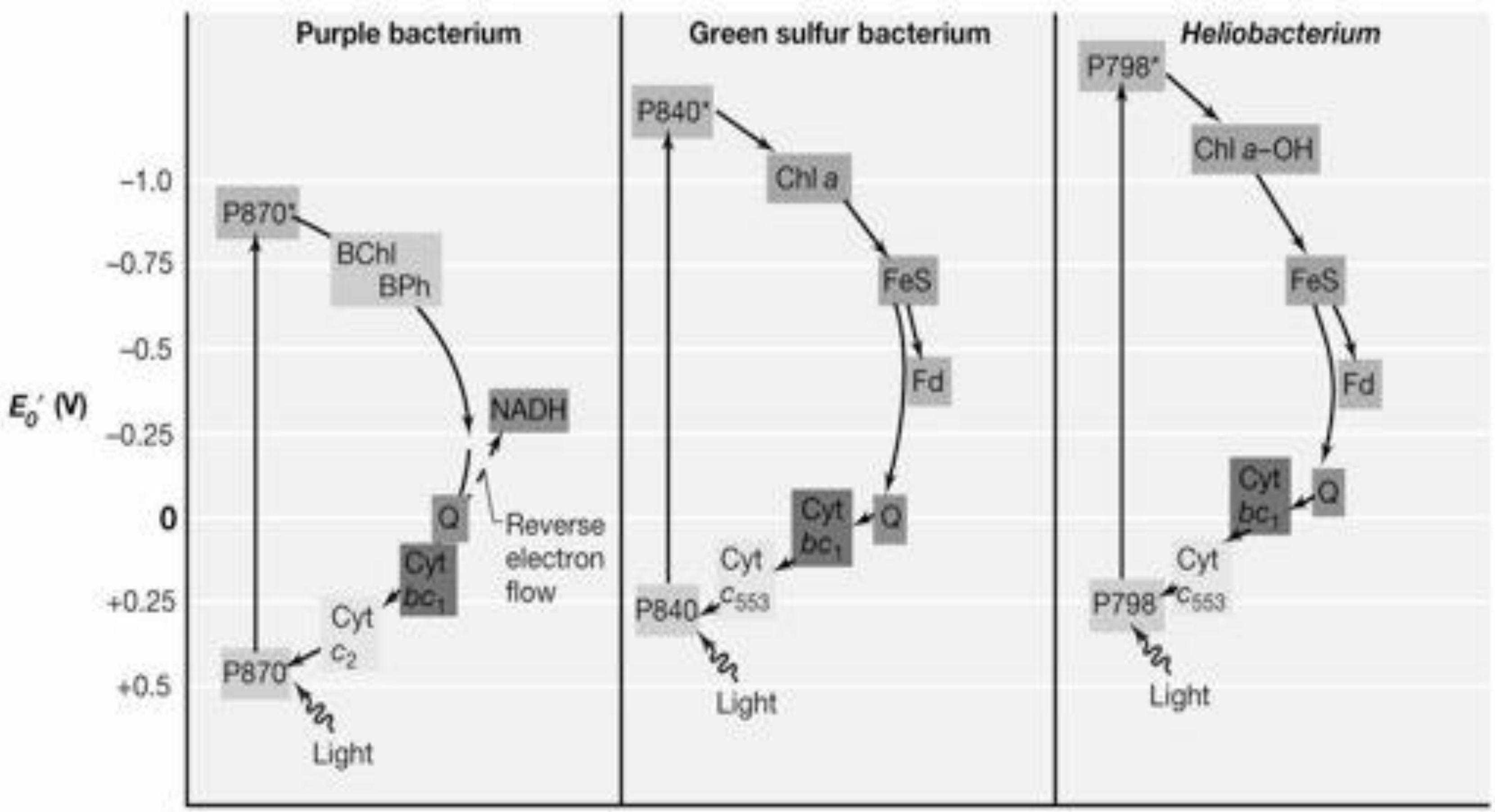
  and

- heliobacteria have a homodimeric type I photosystem;
- Cyanobacteria contain a type I photosystem and an oxygen-evolving type II photosystem, both of which are heterodimeric.

Physiological properties of phototrophic Bacteria

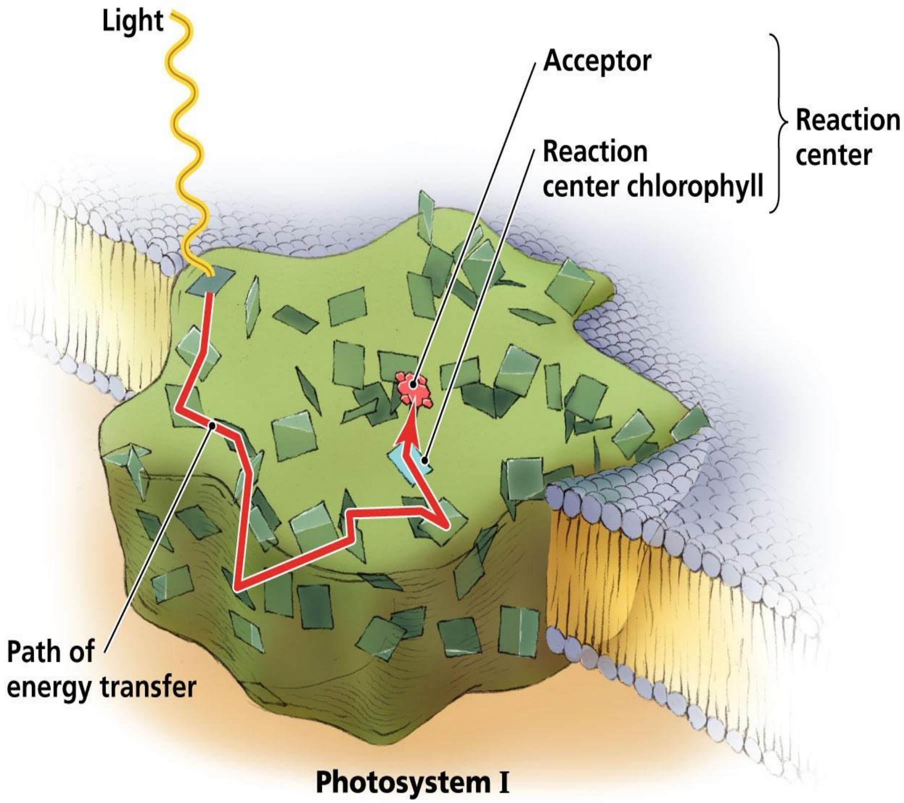
	Cyanobacteria	Purplebacteria	Green Sulfur bacteria	Green non-Sulfur bacteria	Heliobacter
PS-type	PS I and II	PS II	PS I	PS II	PS I
Pigments	Chl a (b)	BChl a, b	BChl a, c, (d, e)	BChl a, c	BCHl g
Autotrophy	+	(+)	+	+/-	-(?)
Physiology	Photoauto- Lithoauto-	Photoauto- Lithoauto- Organohetero-	Photoauto- Lithoauto-	Photoauto- Lithoauto- Organohetero-	Photoauto- Organohetero-
CO_2 fixation	Calvin-cycle	Calvin-cycle	Reductive TCA	3OH-Propionate	None ?
Electron donor	H_2O	H_2S/ organic	H_2S	H_2/ organic	Organic

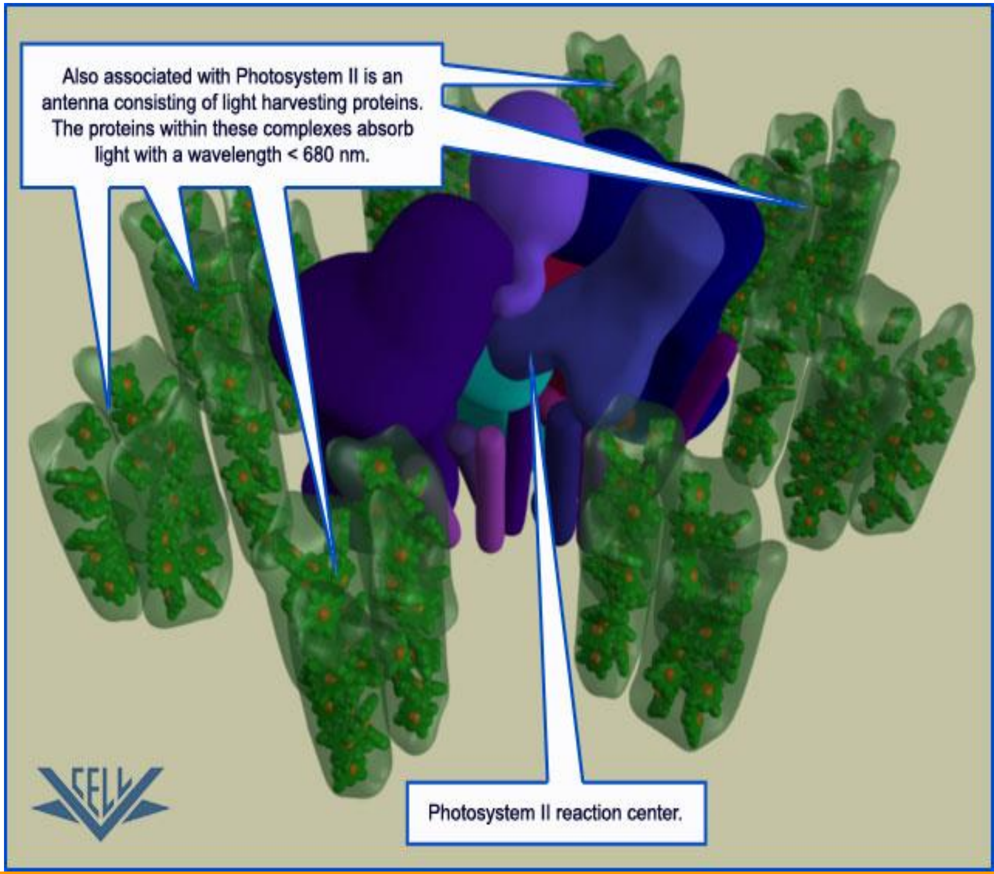
Adapted from Fuchs and Schlegel
'Allgemeine Mikrobiologie'

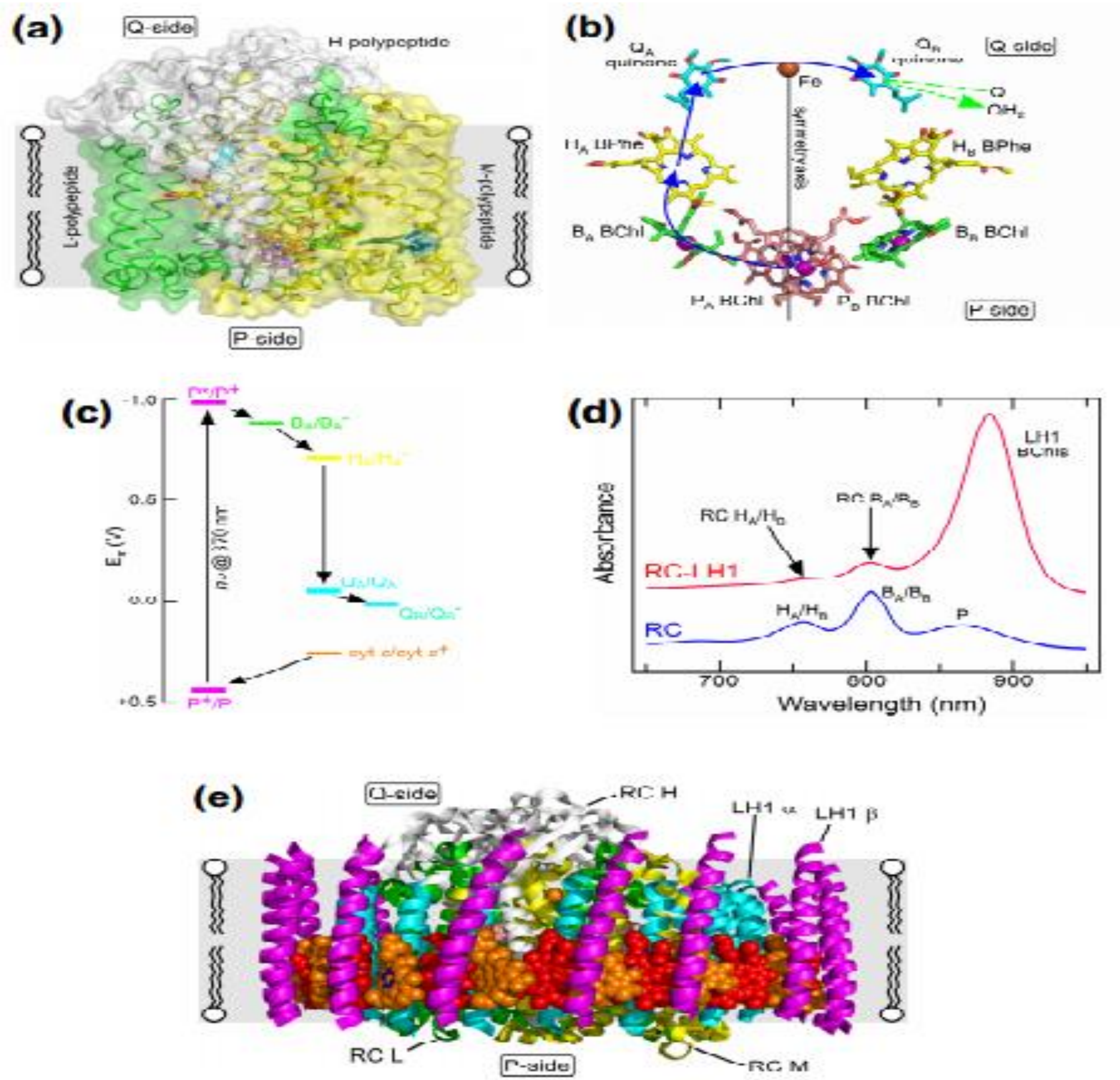


Comparison of electron flow

- Photosynthesis takes place on the surface of the cell



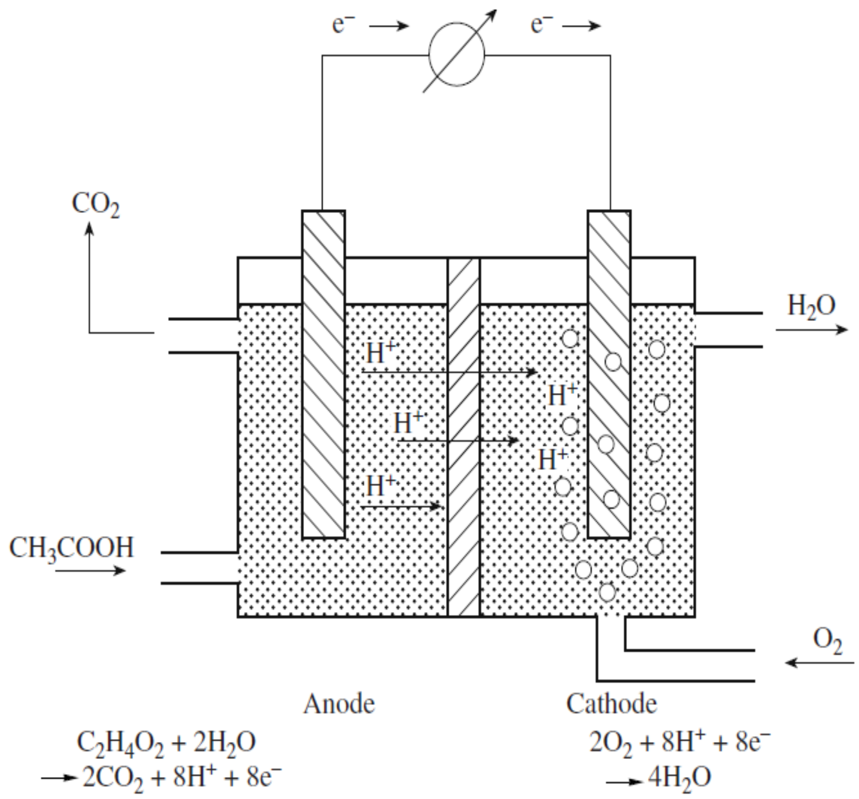




Magis, 2010, Shedding light on surface-assembled photosynthetic systems Langmuir 27:10282-10294

- Solar energy reaches the Earth at the rate of the 178,000 TW of which 0.2% to 0.3% is harnessed by microorganisms

- Microbial fuel cells, a type of bio-electrochemical system, directly capture electrons



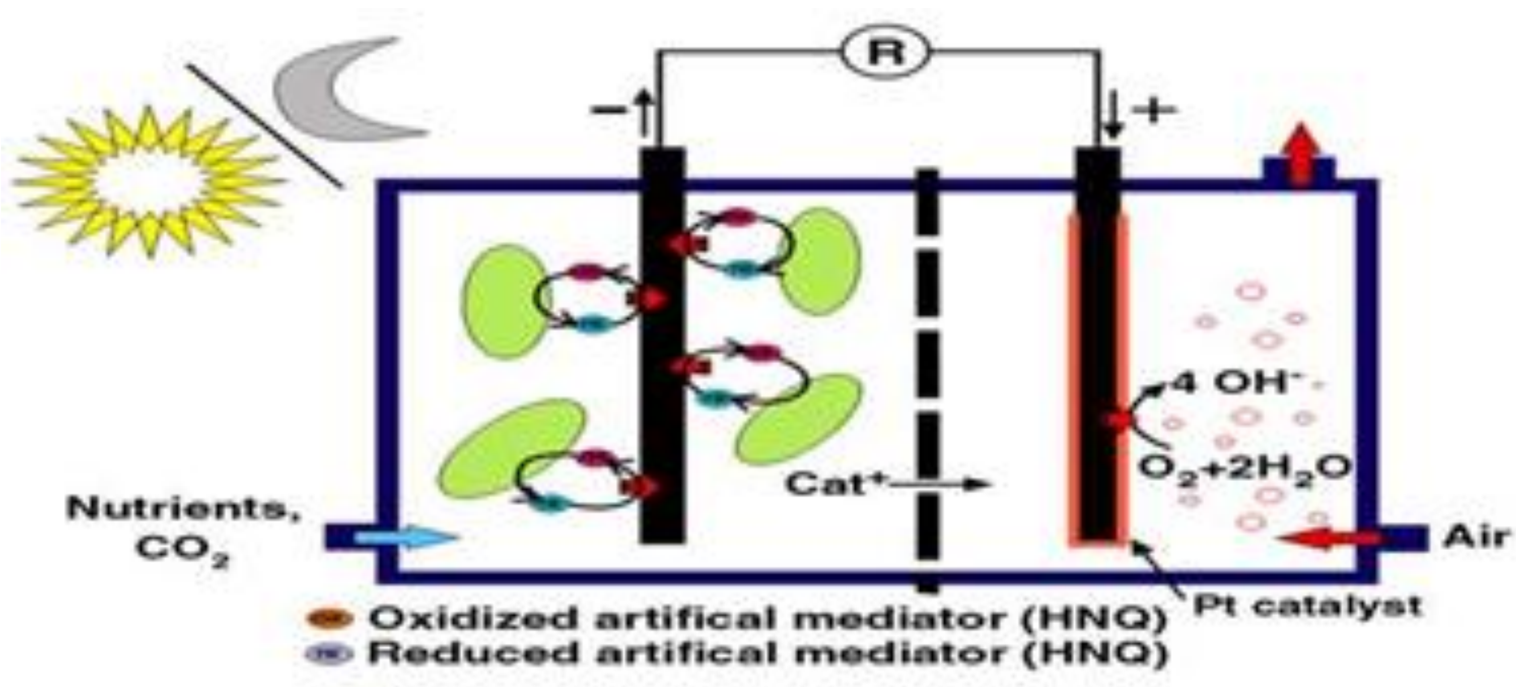
- the oxidation of a carbon source occurs at the anode while the reduction of O2 to H2O occurs at the cathode

Species studied by the researchers in anode chamber.

S. no.	Species	References
1.	*E. coli*	Potter [14], Zhang et al. [15], Habermann and Pommer [22], Zou et al. [59], Park and Zeikus [60], Qiao et al. [61], Xi and Sun [62]
2.	*Shewanella oneidensis* DSP10	Ringeisen et al. [16], Biffinger et al. [18,19]
3.	*Shewanella oneidensis* MR-1	Manohar et al. [17], Biffinger et al. [18]
4.	*Shewanella putrefaciens*	Kim et al. [1], Park and Zeikus [21]
5.	*Pseudomonas aeruginosa*	Habermann and Pommer [22], Rabaey et al. [23–24]
6.	*Geobacter sulfurreducens*	Bond et al. [26], Reguera et al. [27,31], Trinh et al. [33]
7.	*Geobacteraceae*	Holmes et al. [29], Bond et al. [30]
8.	*Geobacter metallireducens*	Min et al. [32]
9.	*Dessulfobulbus propionicus*	Lovley et al. [53]
10.	*Geothrix fermentans*	Lovley et al. [54]
11.	*Paracoccus denitrificans* and *Paracoccus pantotrophus*	Rabaey et al. [55]
12.	*Rhodopseudomonas palustris* DX-1	Xing et al. [56]
13.	*Klebsiella pneumoniae*	Lewandowski et al. [57,58]

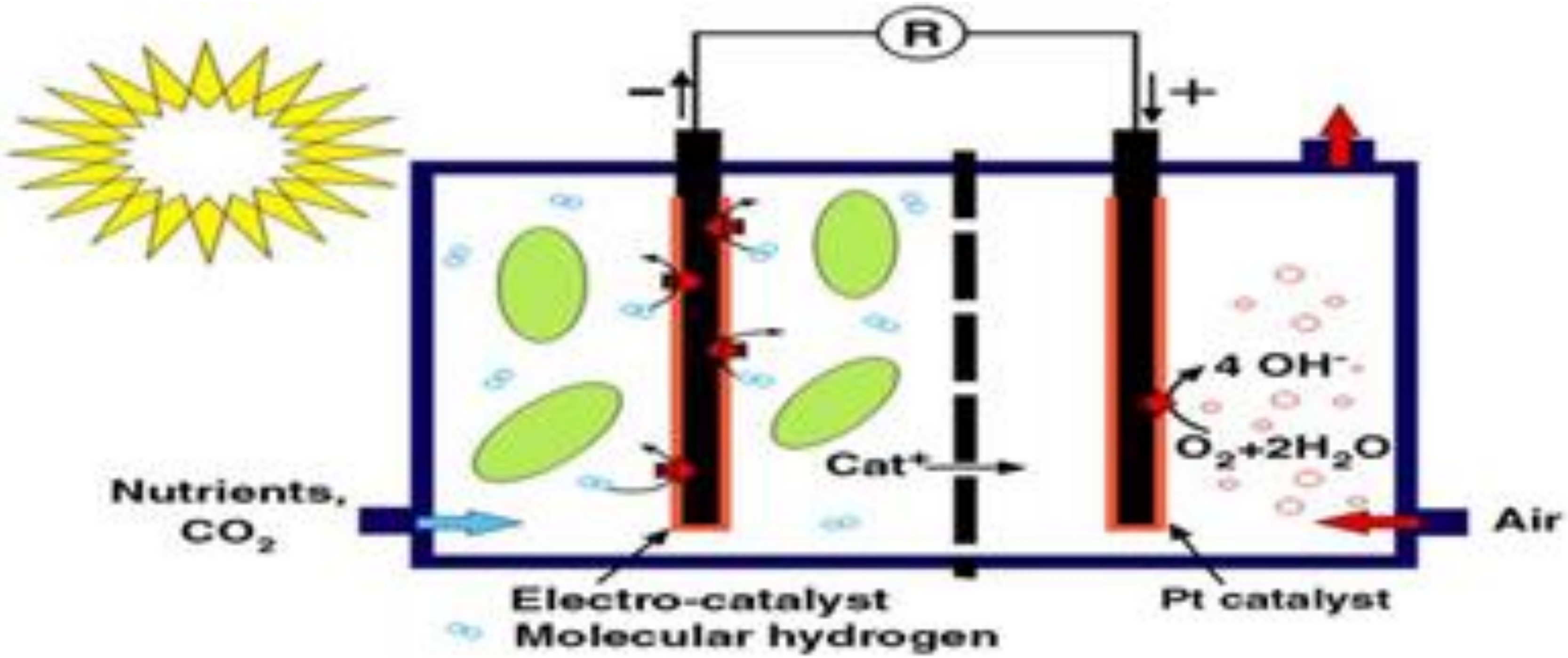
- The photosynthetic microbial fuel cell (PMFC) is a bioelectrochemical system capable of converting sunlight into electricity based on the exploitation of biocatalytic reactions within active microbial cells

Photosynthetic bacteria at the anode with artificial mediators



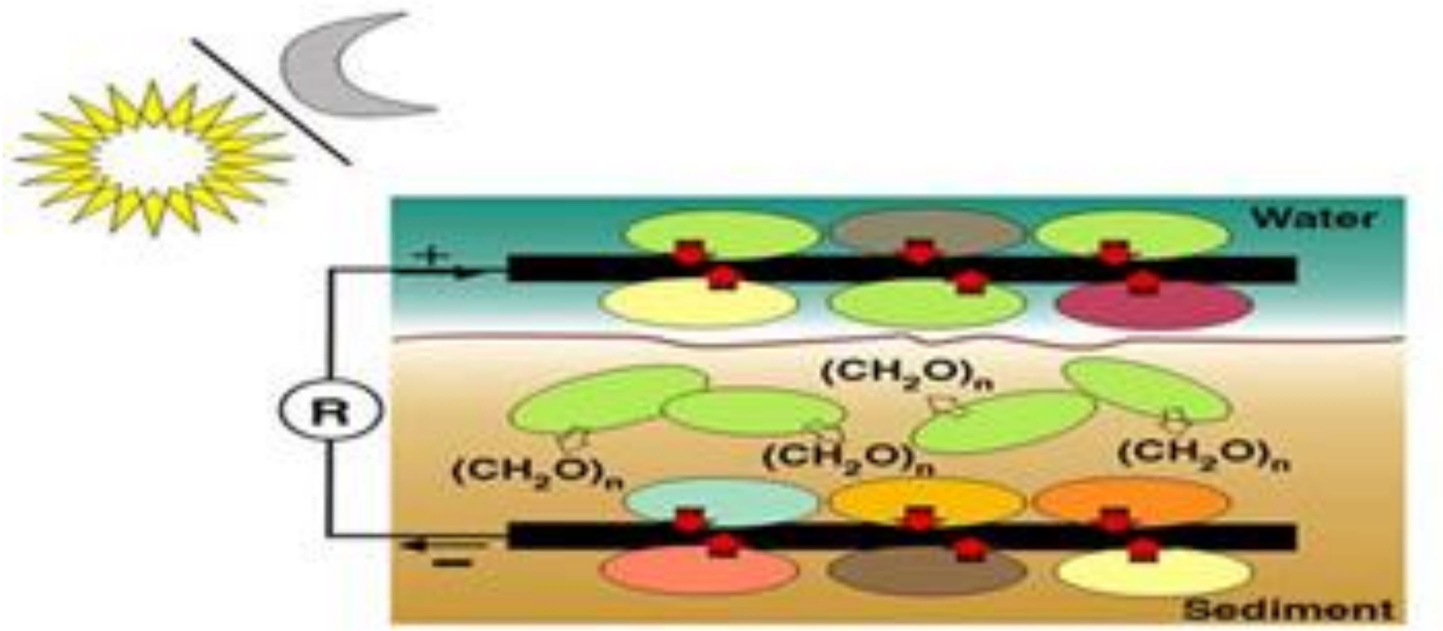
2-hydroxy-1,4-naphtoquinone

- Hydrogen-generating photosynthetic bacteria with an electrocatalytic anode

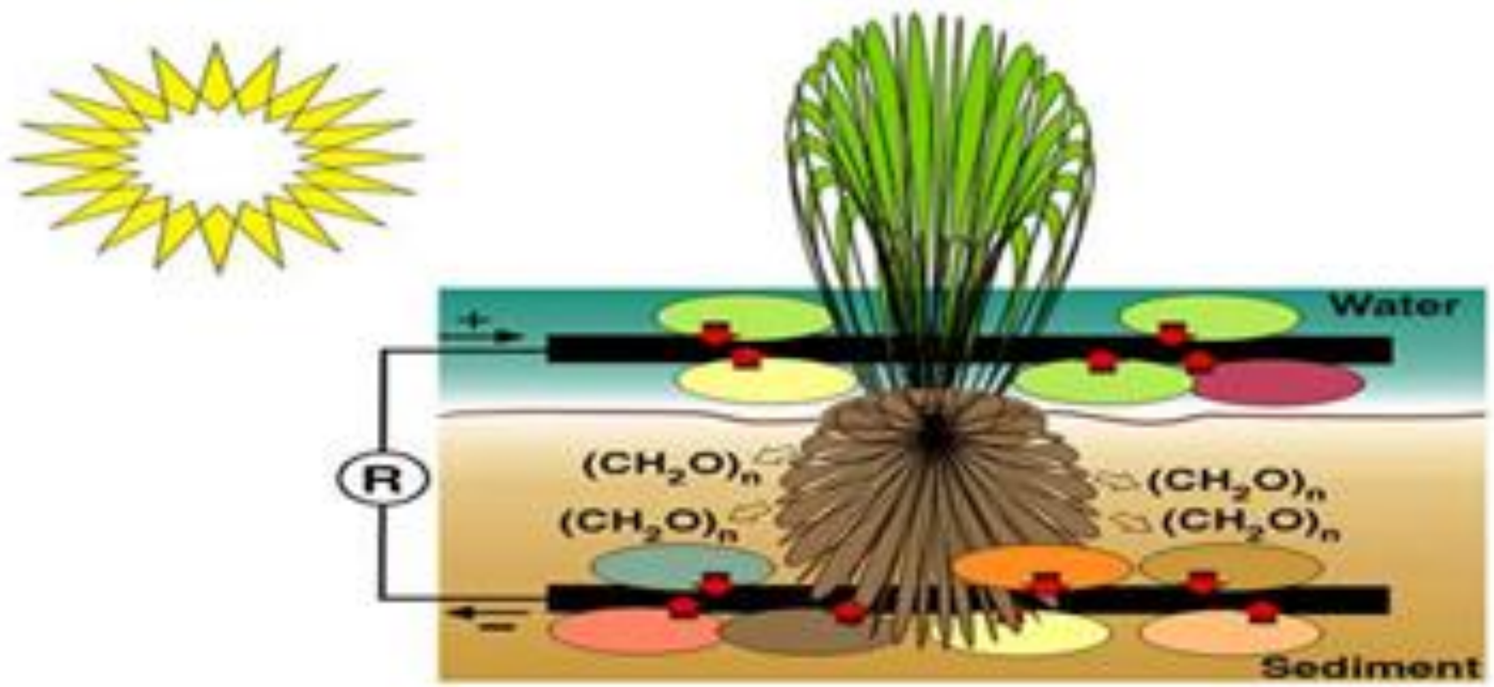


Photosynthesis coupled with mixed heterotrophic bacteria at the anode

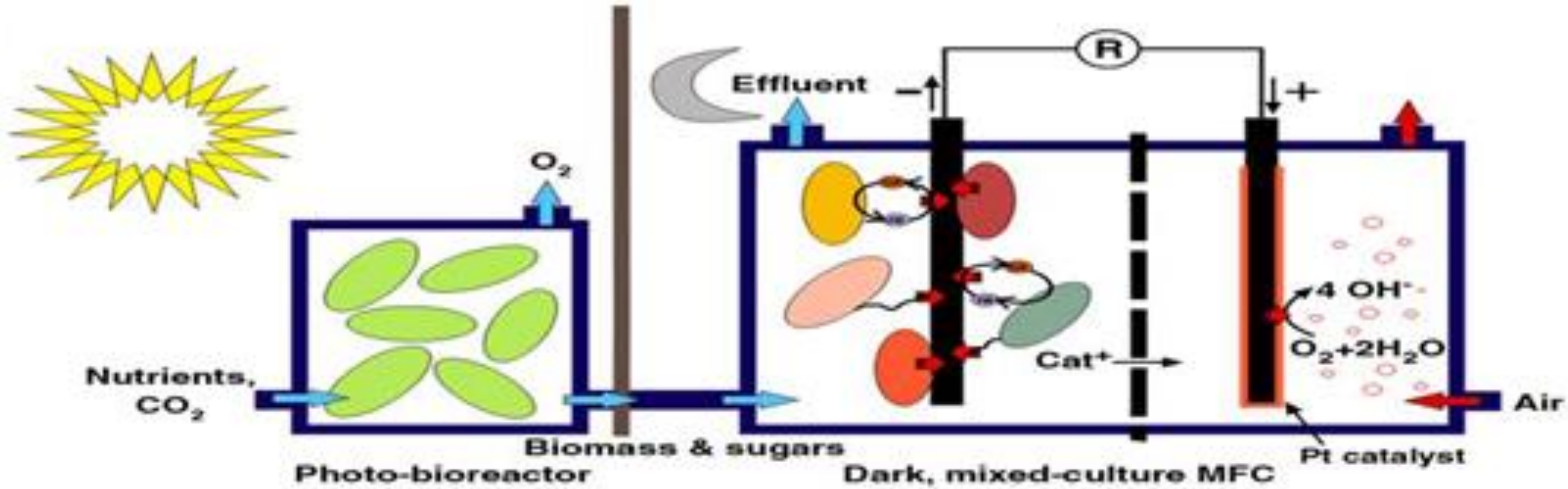
- Synergism between phototrophic microorganisms and mixed heterotrophic bacteria in sediments



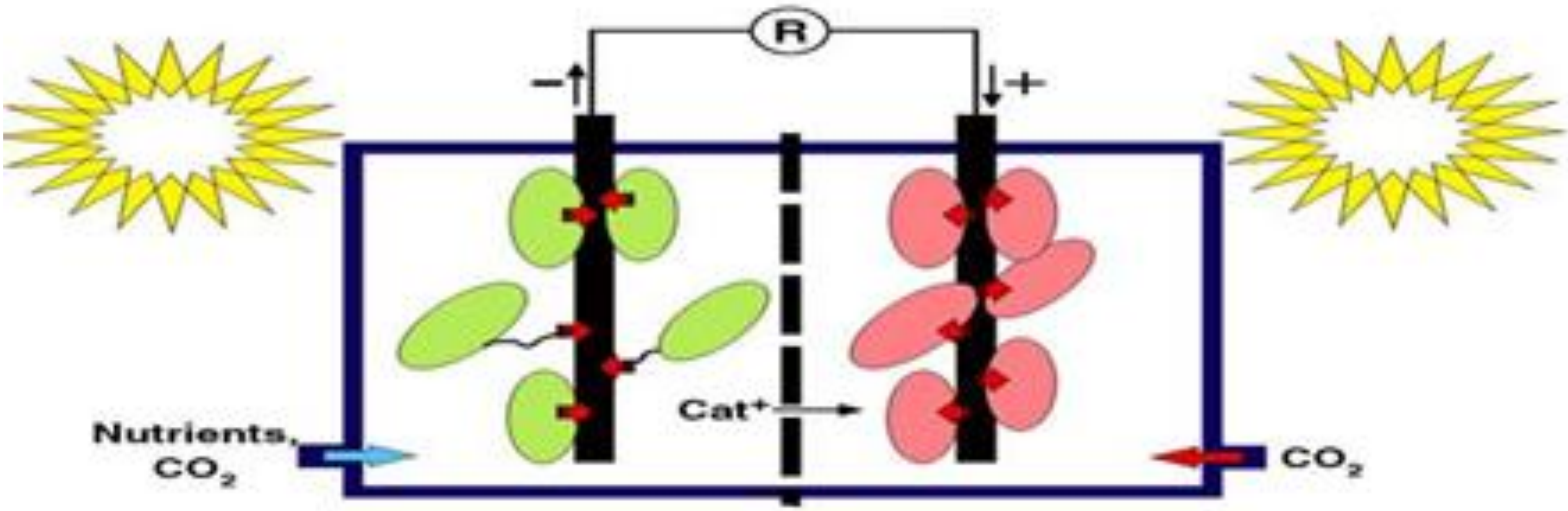
- Synergism between plants and mixed heterotrophic bacteria in sediments



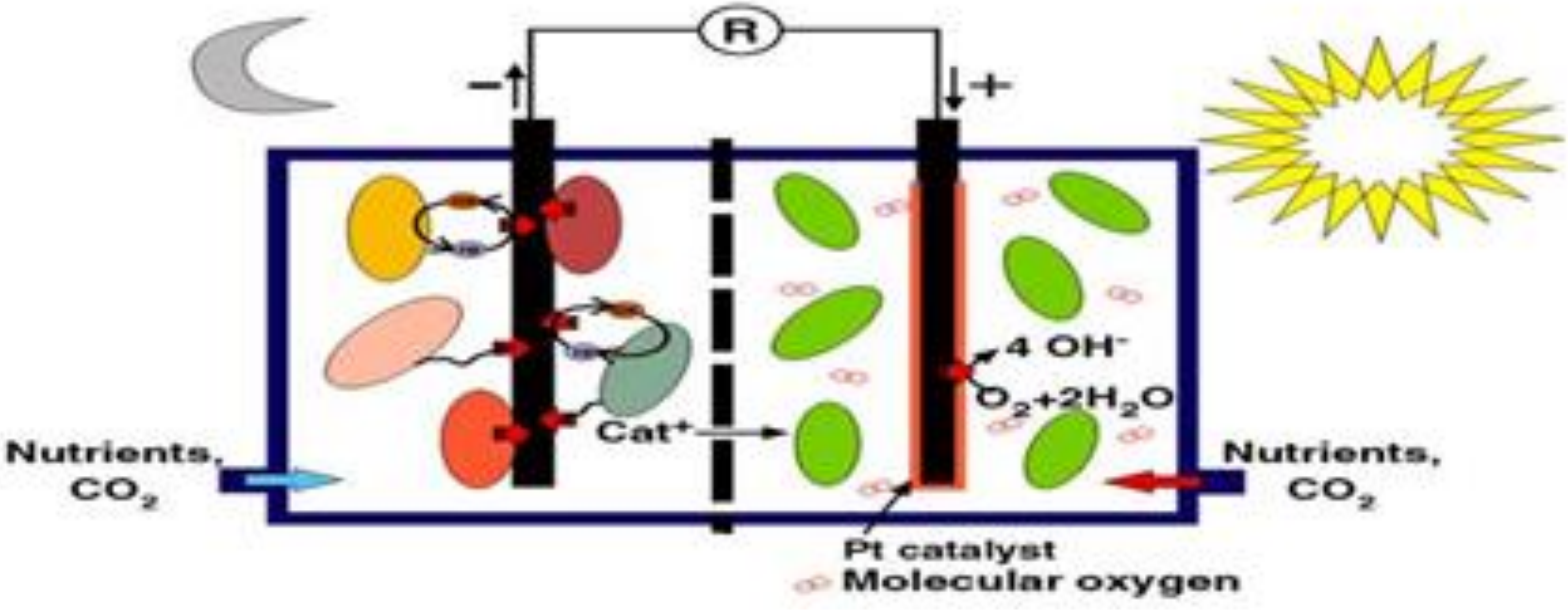
- Ex situ photosynthesis coupled with mixed heterotrophic bacteria at a dark anode



- Direct electron transfer between photosynthetic bacteria and electrodes



- Photosynthesis at the cathode to provide oxygen

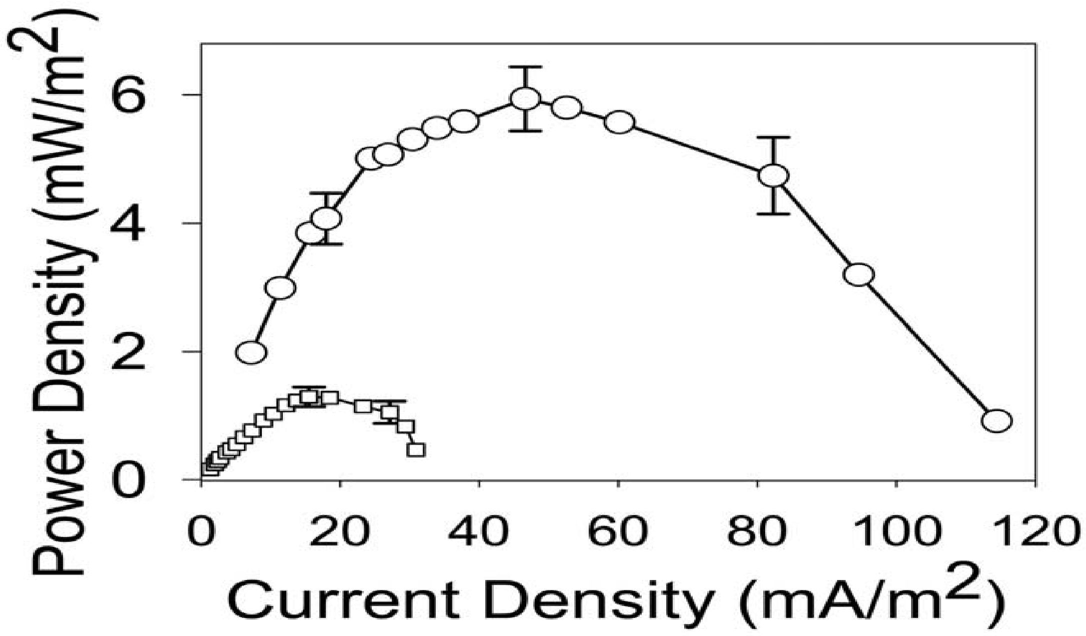


Electrogenic yield of diverse cyanobacteria genera and mixed pond consortium.

Culture	Yield, % [1]
Pond consortium	0.304±0.009
Calothrix	0.265±0.006
Pseudoanabaena	0.165±0.008
Synechococcus	0.155±0.006
Ananbaena	0.149±0.015
Phormidium	0.149±0.015
Nostoc	0.136±0.013
Lyngbya	0.130±0.016
Spirulina	0.099±0.09
Synechocystis	0.075±.008
Leptolyngbya	0.051±0.015

[1] The yield is shown as a mean of three 24 h illumination cycles with' a standard deviation.

Pisciotta JM, Zou Y, Baskakov IV (2010) Light-Dependent Electrogenic Activity of Cyanobacteria. PLoS ONE 5(5): e10821. doi:10.1371/journal.pone.0010821



Effect of anode material on electron harvesting. Power density curves (normalized by the cathode surface area = 9.6 cm2) measured for MFC with mixed photosynthetic biofilm consortium formed on anode coated with polypyrrole (%) or nanostructured polypyrrole

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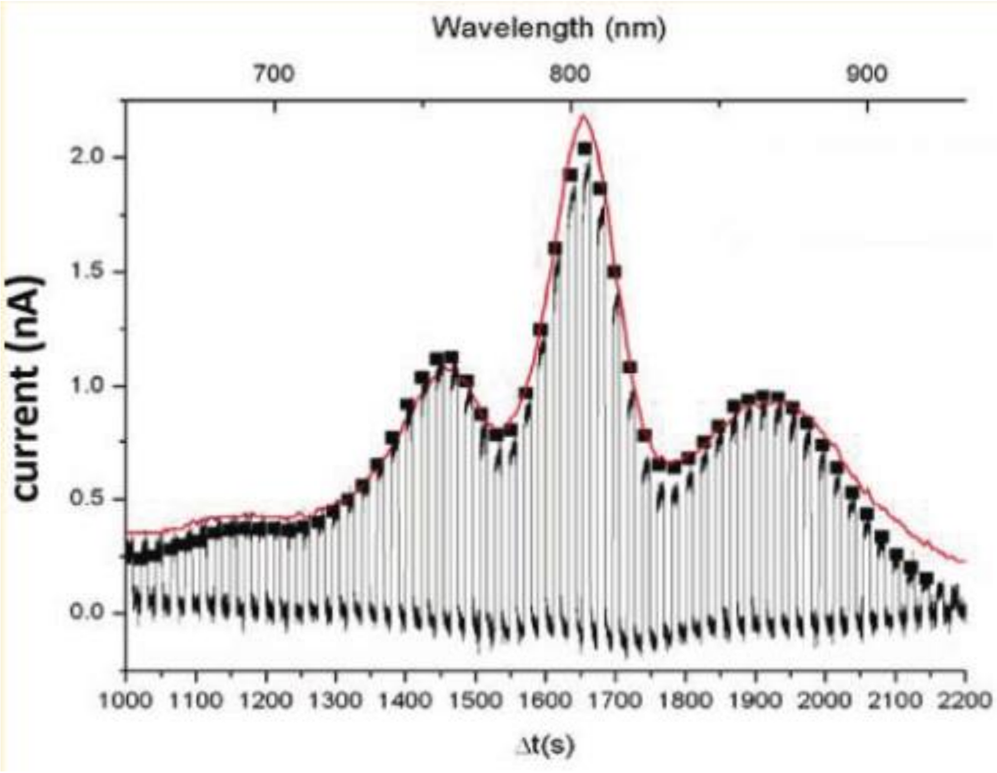
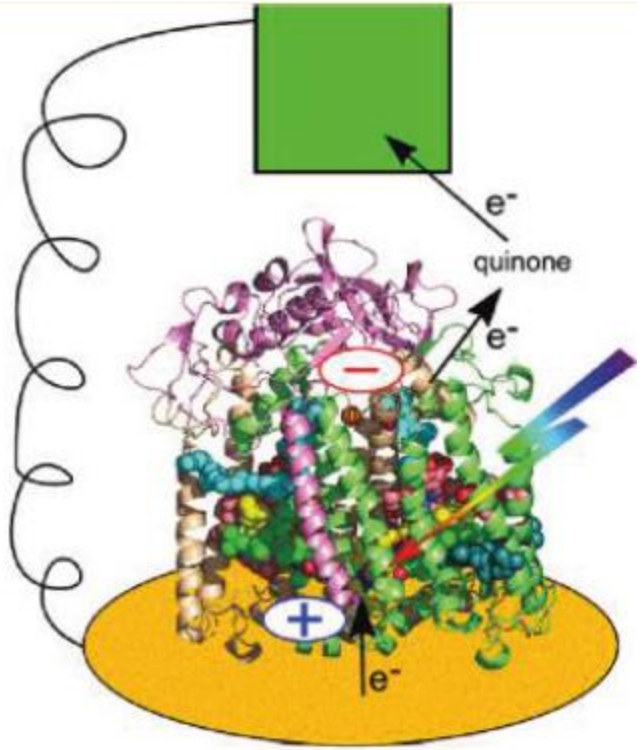

Wavelength (nm)
700
800
900
current (nA)
2.0
1.5
1.0
0.5
0.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
Δt(s)


e⁻
quinone
e⁻
e⁻

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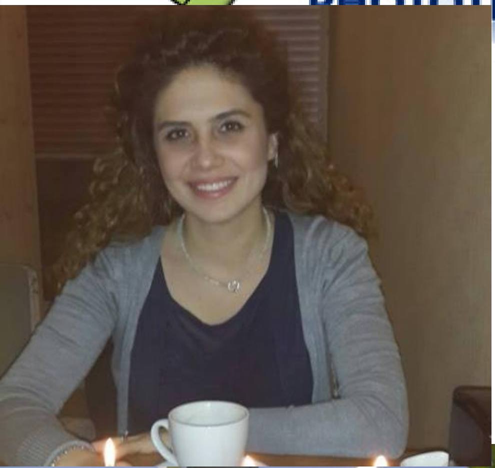

- Thank you for your attention!!!

References

Pisciotta JM, Zou Y, Baskakov IV (2010) Light-Dependent Electrogenic Activity of Cyanobacteria. PLoS ONE 5(5): e10821. doi:10.1371/journal.pone.0010821

Rosenbaum M., He Z., Angenent, LT. 2010, Light energy to bioelectricity: photosynthetic microbial fuel cells. Current Opinion in Biotechnology, 21:259–264