

FOTOSINTESI

- Problema energetico
- Fotosintesi naturale
- Fotosintesi artificiale, unità funzionali

ENERGIA
kJ, kcal

POTENZA
 $kW = \text{kJ/s}$

Watt

1 W



Kilowatt

$1000 \text{ W} = 1 \text{ KW}$



Megawatt

$$1\ 000\ 000\ \text{W} = 1000\ \text{KW} = 1\ \text{MW}$$

$$600\ \text{KW} = 0.6\ \text{MW}$$



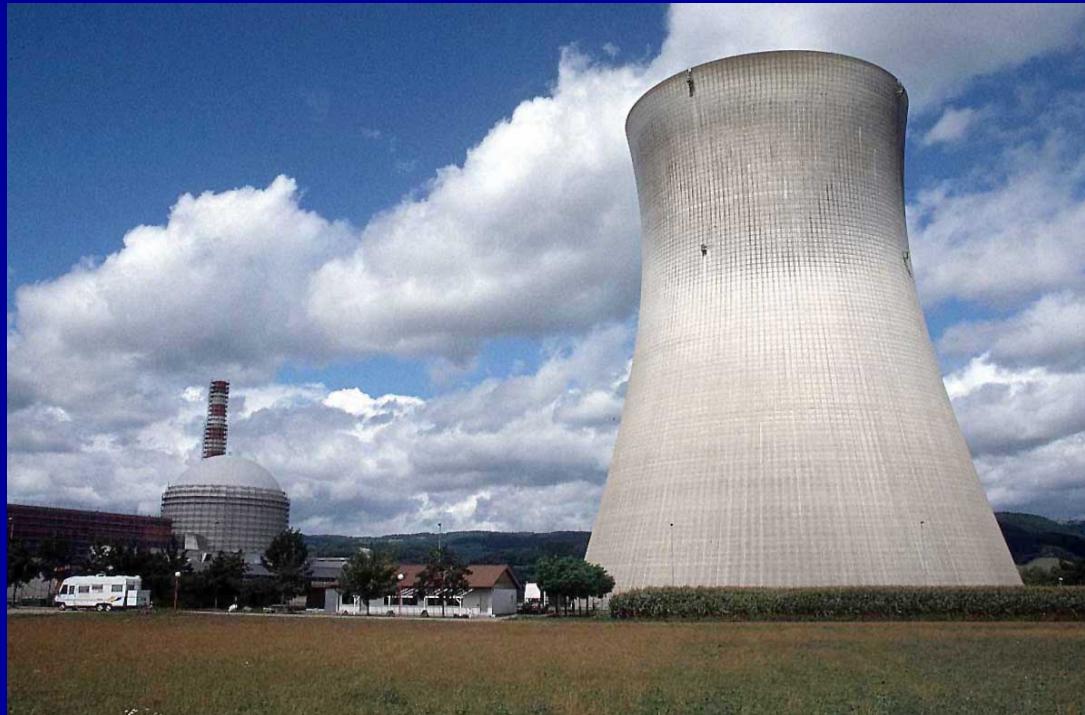
Ferrari F2009 - 2009 aero mockup

Scott Thomson (Scottracer)



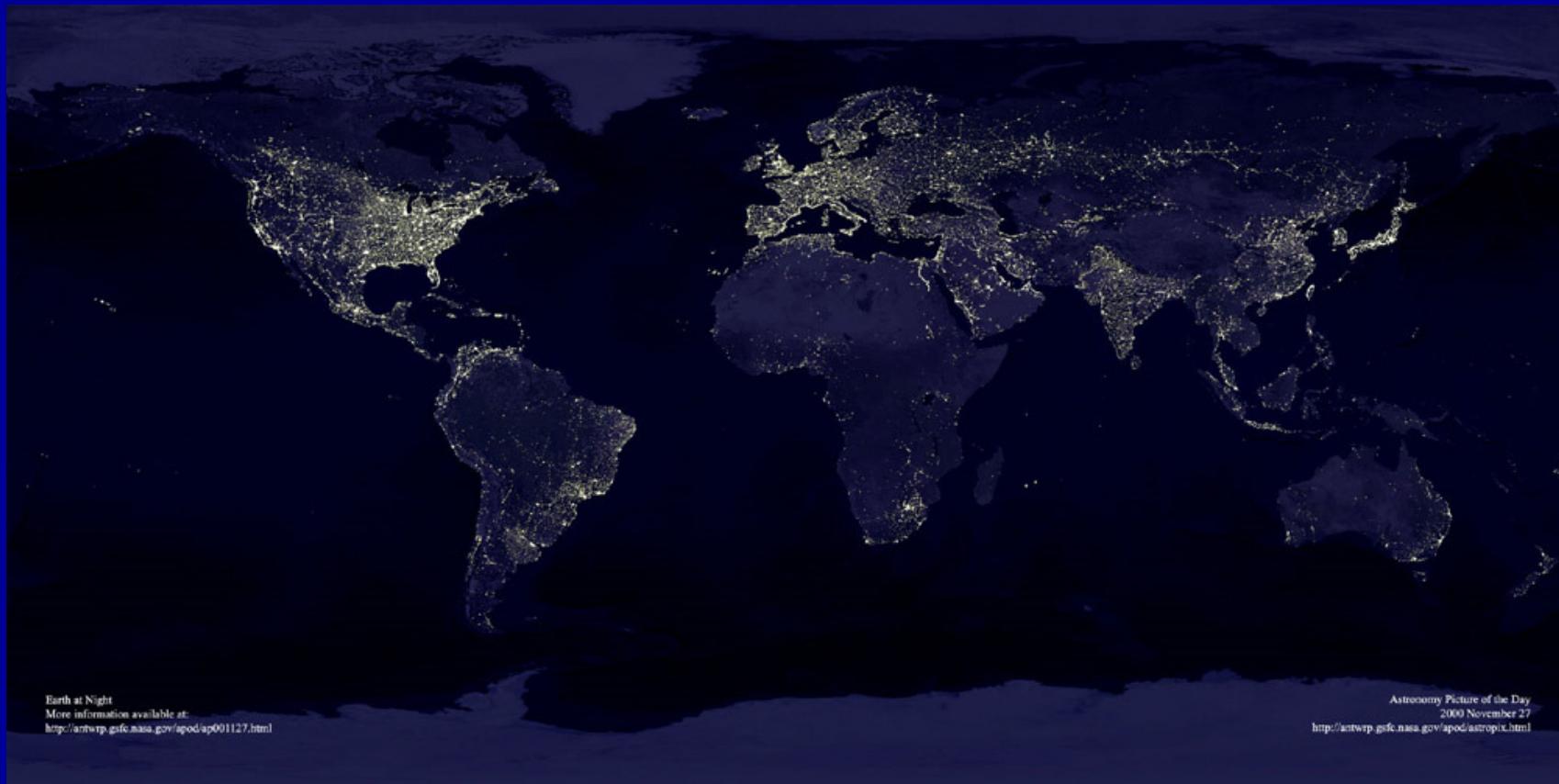
Gigawatt

$1\ 000\ 000\ 000\ \text{W} = 1\ 000\ 000\ \text{kW} = 1000\ \text{MW} = 1\ \text{GW}$



Terawatt

$$1000 \text{ GW} = 1 \text{ TW}$$



Earth at Night
More information available at:
<http://antwrp.gsfc.nasa.gov/apod/ap001127.html>

Astronomy Picture of the Day
2000 November 27
<http://antwrp.gsfc.nasa.gov/apod/astropix.html>

2009

Popolazione = 6.5 miliardi

Consumo energetico = 13 TW

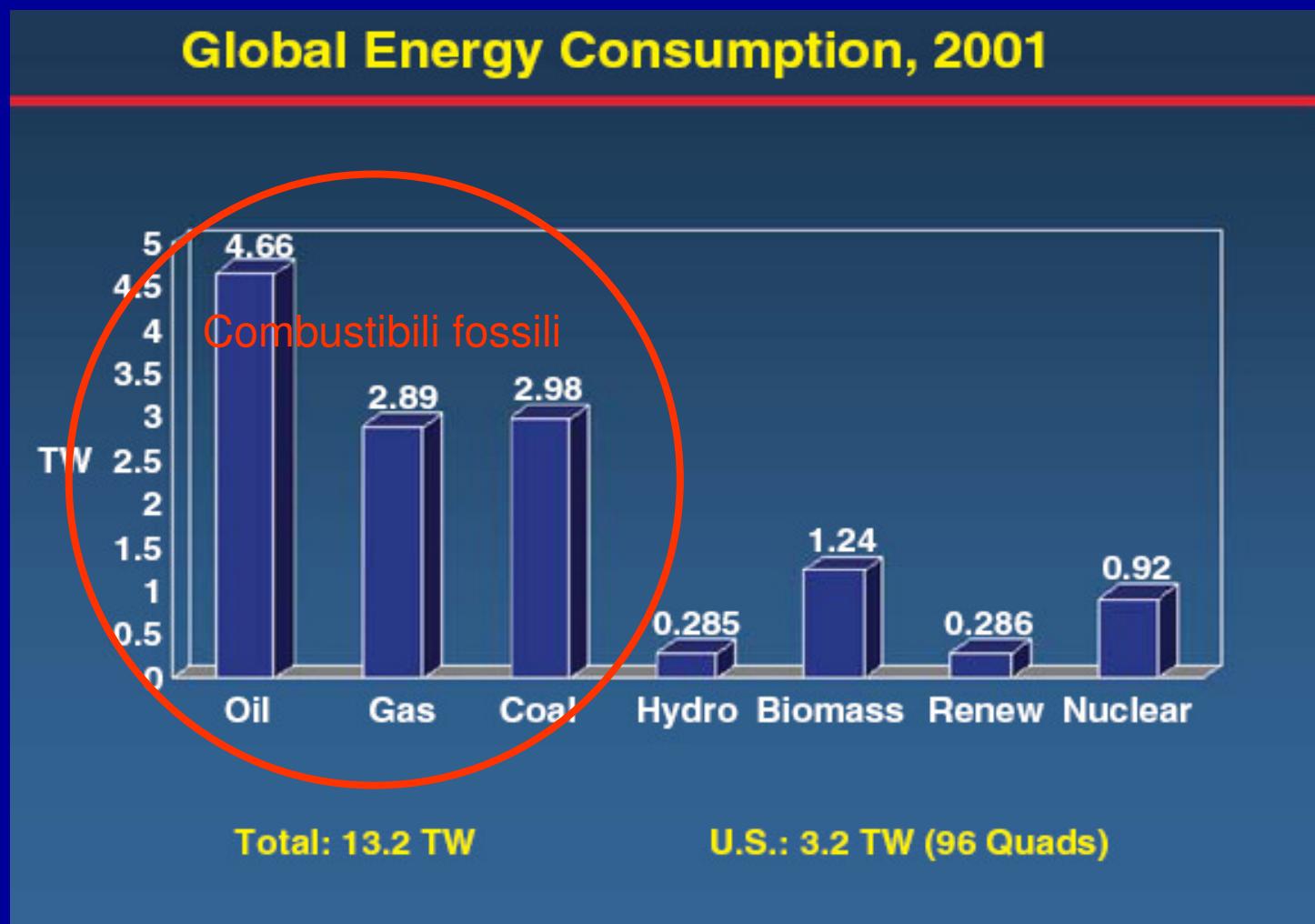
2050

Popolazione = 9.4 miliardi

Consumo energetico = 27 TW



Da dove viene l'energia che usiamo?



L'energia viene usata per.....



.. ma è **contenuta in** quasi tutto ciò che utilizziamo (perché è servita a produrlo).

Ogni cosa ha un “equivalente in petrolio”



=



=



COMBUSTIBILI FOSSILI

- derivanti dalla trasformazione sviluppatasi in milioni di anni, di sostanza organica (fitoplancton, zooplankton) depositatasi nel fondo di mare/laghi, seppellitasi sottoterra nel corso delle ere geologiche, in forme molecolari via via più stabili e ricche di carbonio.
- 1 litro di benzina è il risultato di circa 23 tonnellate di materiale organico originariamente depositato



Graphic adapted from:
Paleontological Research Institution

January	February	March
1 2 3 4 5 6 7	1 2 3 4	1 2 3 4
8 9 10 11 12 13 14	5 6 7 8 9 10 11	5 6 7 8 9 10 11
15 16 17 18 19 20 21	12 13 14 15 16 17 18	12 13 14 15 16 17 18
22 23 24 25 26 27 28	19 20 21 22 23 24 25	19 20 21 22 23 24 25
29 30 31	26 27 28	26 27 28 29 30 31
April	May	June
1	1 2 3 4 5 6	1 2 3
2 3 4 5 6 7 8	7 8 9 10 11 12 13	4 5 6 7 8 9 10
9 10 11 12 13 14 15	14 15 16 17 18 19 20	11 12 13 14 15 16 17
16 17 18 19 20 21 22	21 22 23 24 25 26 27	18 19 20 21 22 23 24
23 24 25 26 27 28 29	28 29 30 31	25 26 27 28 29 30
30		
July	August	September
1	1 2 3 4 5	1 2
2 3 4 5 6 7 8	6 7 8 9 10 11 12	3 4 5 6 7 8 9
9 10 11 12 13 14 15	13 14 15 16 17 18 19	10 11 12 13 14 15 16
16 17 18 19 20 21 22	20 21 22 23 24 25 26	17 18 19 20 21 22 23
23 24 25 26 27 28 29	27 28 29 30 31	24 25 26 27 28 29 30
30 31		
October	November	December
1 2 3 4 5 6 7	1 2 3 4	1 2
8 9 10 11 12 13 14	5 6 7 8 9 10 11	3 4 5 6 7 8 9
15 16 17 18 19 20 21	12 13 14 15 16 17 18	10 11 12 13 14 15 16
22 23 24 25 26 27 28	19 20 21 22 23 24 25	17 18 19 20 21 22 23
29 30 31	26 27 28 29 30	24 25 26 27 28 29 30
		31

- Earth is formed
 - Life emerges
 - Photosynthesis
 - Cyanobacteria
 - Oxygen-rich atmosphere
 - Plants
 - Dinosaurs
 - Hominids, 3pm
 - Homo Sapiens, 11:38 pm
 - US 11:59:58 pm
- Age of Earth 4.55 billion yrs

Combustibili fossili

Quanto ce n'è?

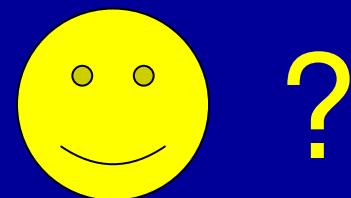
Per quanto possono durare?

Riserve (giacimenti attualmente accessibili):

- 40-80 anni petrolio
- 60-180 anni gas naturale
- > 200 carbone

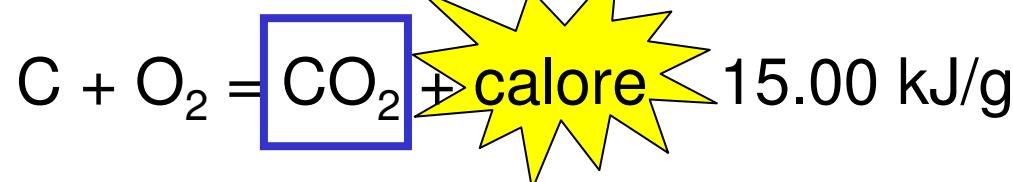
Risorse totali (comprese quelle, stimate, ancora da scoprire):

- 50-150 anni petrolio
- 200-600 anni gas naturale
- ca. 2000 anni carbone

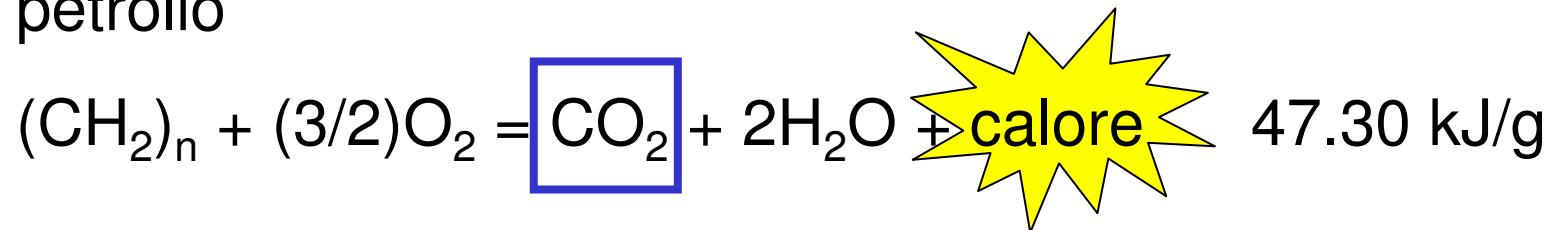


Combustibili fossili, producono ...

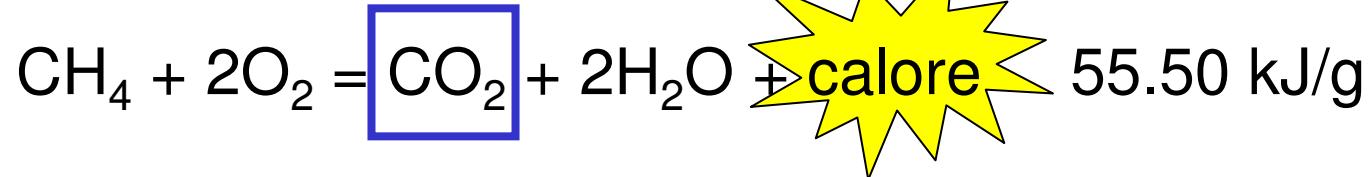
carbone



petrolio

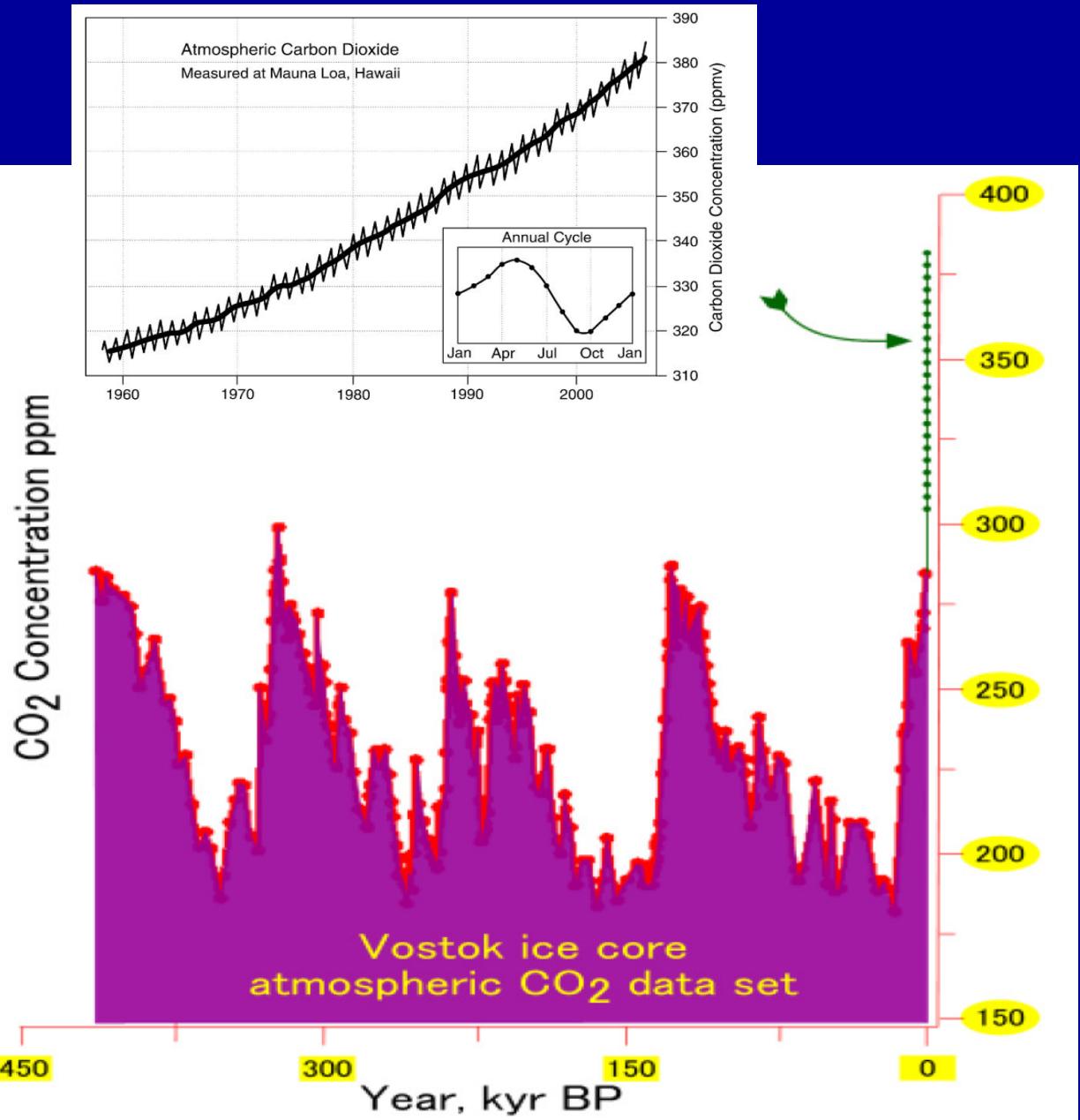


gas



L'anidride carbonica è il principale responsabile dell'effetto serra (riscaldamento globale)



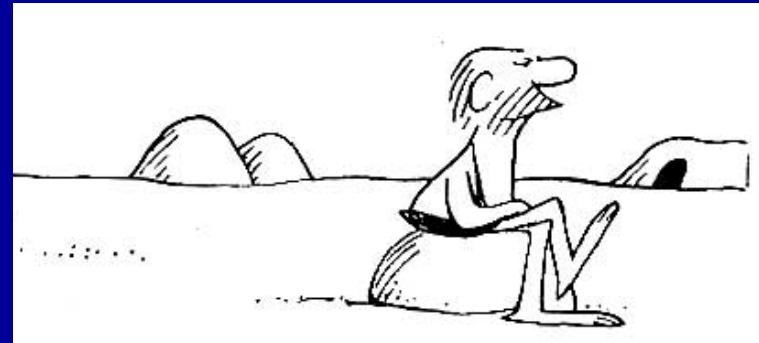




L'uso dei combustibili fossili non può continuare nel modo abituale. Bisogna uscire dall' "era dei combustibili fossili", non tanto (non solo) per la progressiva riduzione delle riserve dei combustibili fossili, ma soprattutto per le conseguenze sull'ecosistema (riscaldamento globale)

"L'età della pietra non è finita perché erano rimasti senza pietre..."

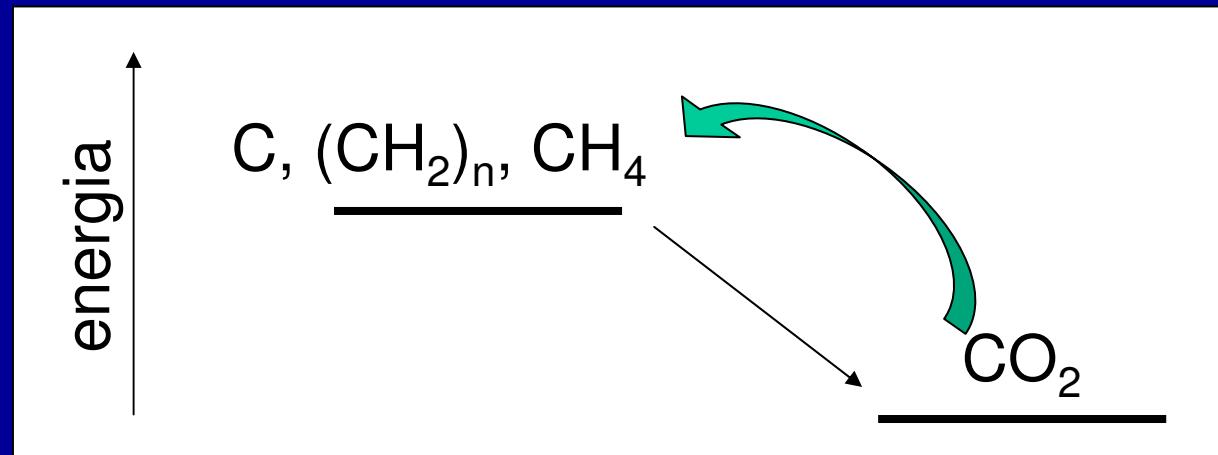
(Richard Sears)



(... ma perché si erano inventati materiali migliori)

L'era dei combustibili fossili deve essere sostituita da quella delle **energie rinnovabili**

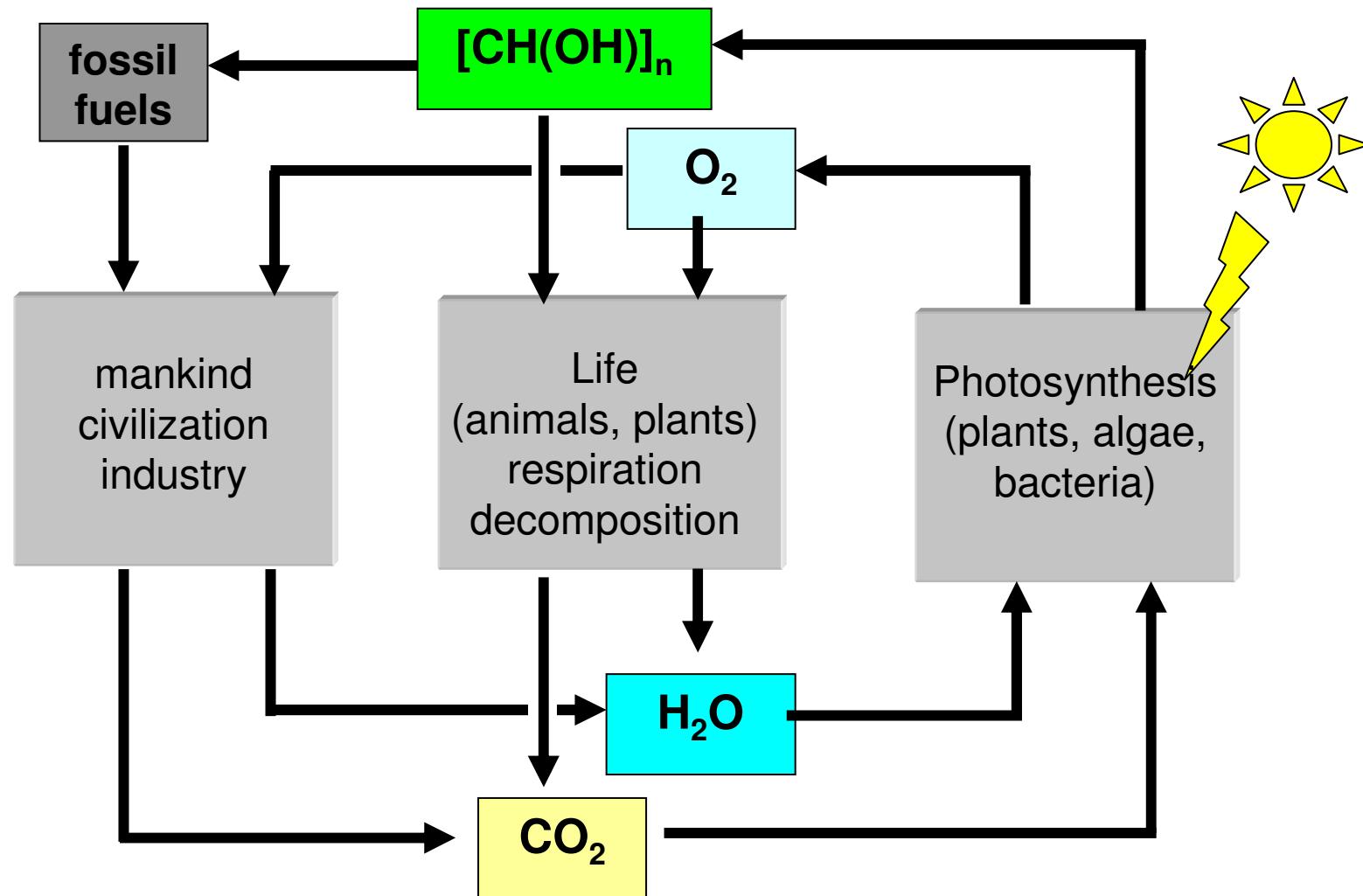
La combustione (ossidazione) del carbonio elementare e dei suoi composti idrogenati (ridotti) in aria è un processo spontaneo, “in discesa” dal punto di vista dell’energia

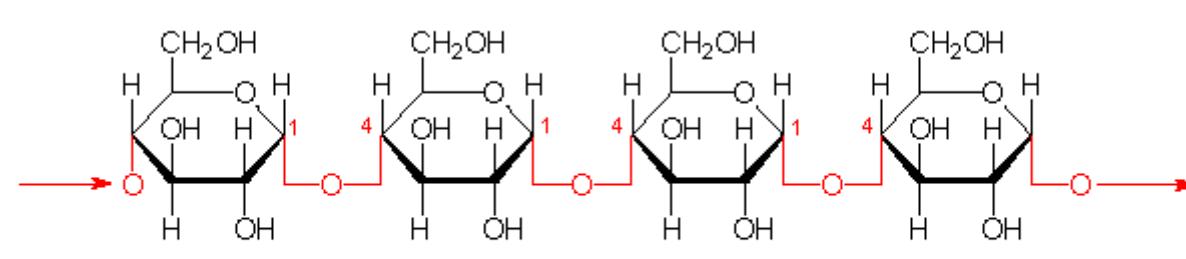


Per riformarli a partire da CO_2 serve un input di energia. In natura...

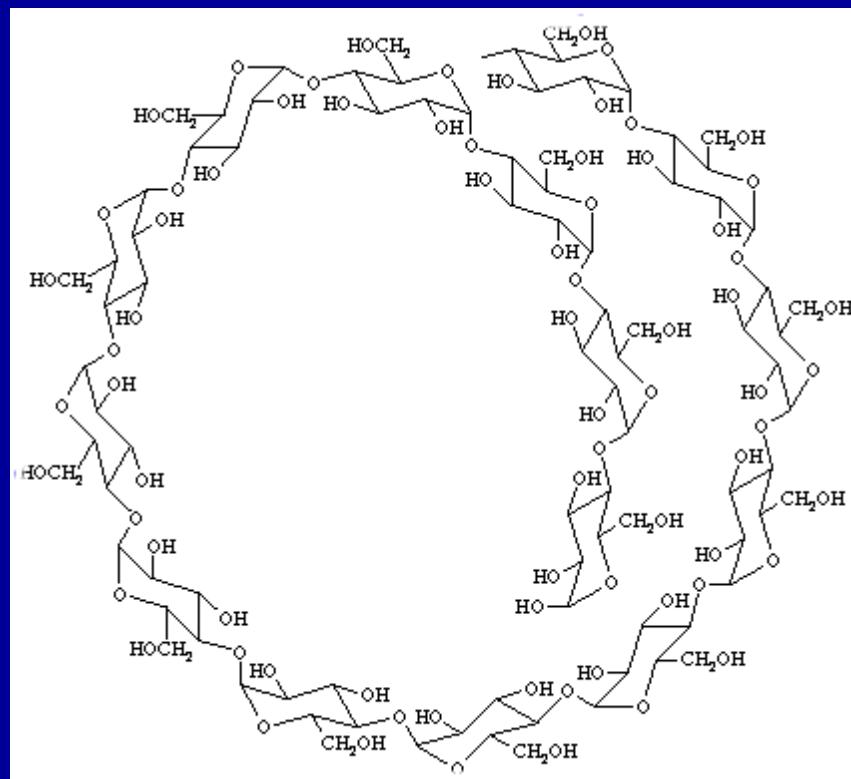


FOTOSINTESI





α - amylose



Buona notizia

Con una stima (conservativa) l'energia solare netta che giunge sulla superficie sulla superficie del pianeta corrisponde a una potenza media di 170.000 TW
Quindi, **l'energia solare teoricamente disponibile è almeno 10.000 volte quella attualmente ottenuta per combustione del petrolio.**

L'energia solare che arriva sulla superficie del pianeta in **meno di un'ora** equivale all'intero **consumo annuale mondiale**

Il fabbisogno corrente potrebbe essere coperto con collettori che occupassero lo **0.2 % della superficie terrestre** e convertissero l'energia solare con efficienza del 10%.





Concentratori solari:

- convertono in calore a alta T



FOTOVOLTAICO



- converte direttamente in elettricità

Cattiva notizia....

L'energia solare è **diluita e intermittente**.

La principale sfida scientifica e tecnologica è quella di **immagazzinare** il gigantesco e diluito flusso di energia solare per poi utilizzarlo con la concentrazione necessaria, dove e quando richiesto.

Occorre **convertire** l'energia solare in **combustibile**



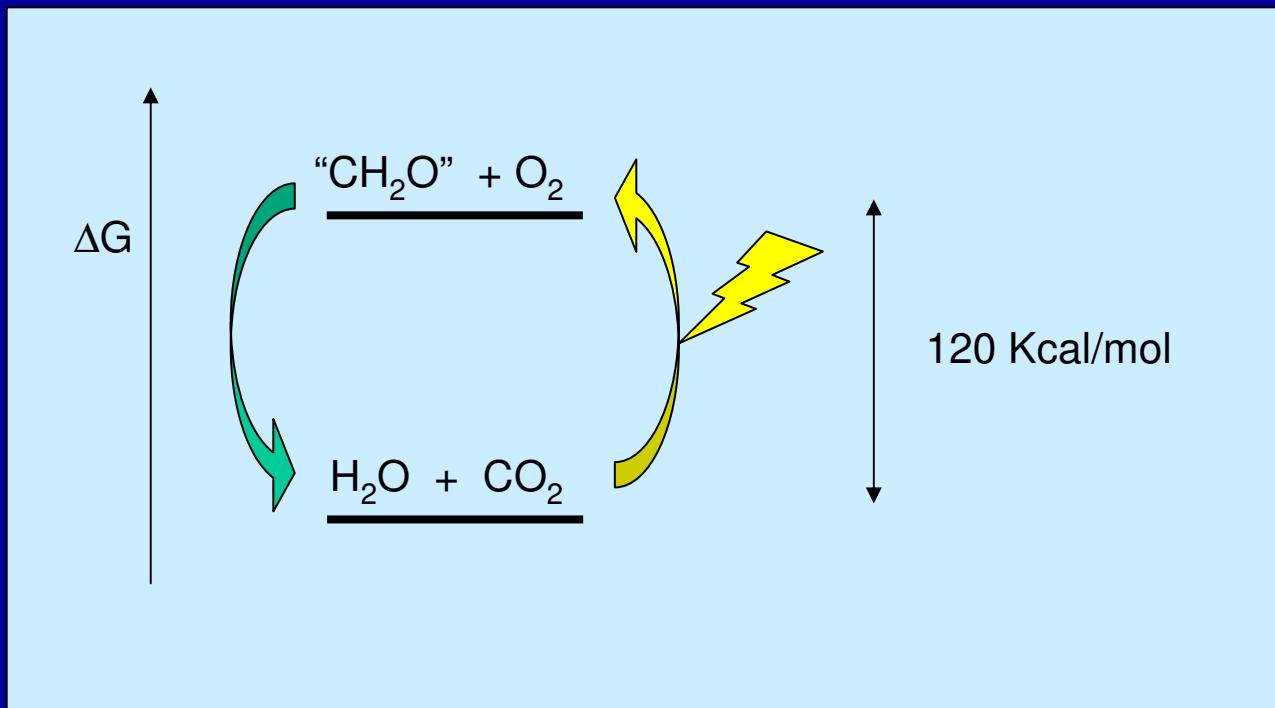
Conversione Chimica (Fotosintesi Artificiale)

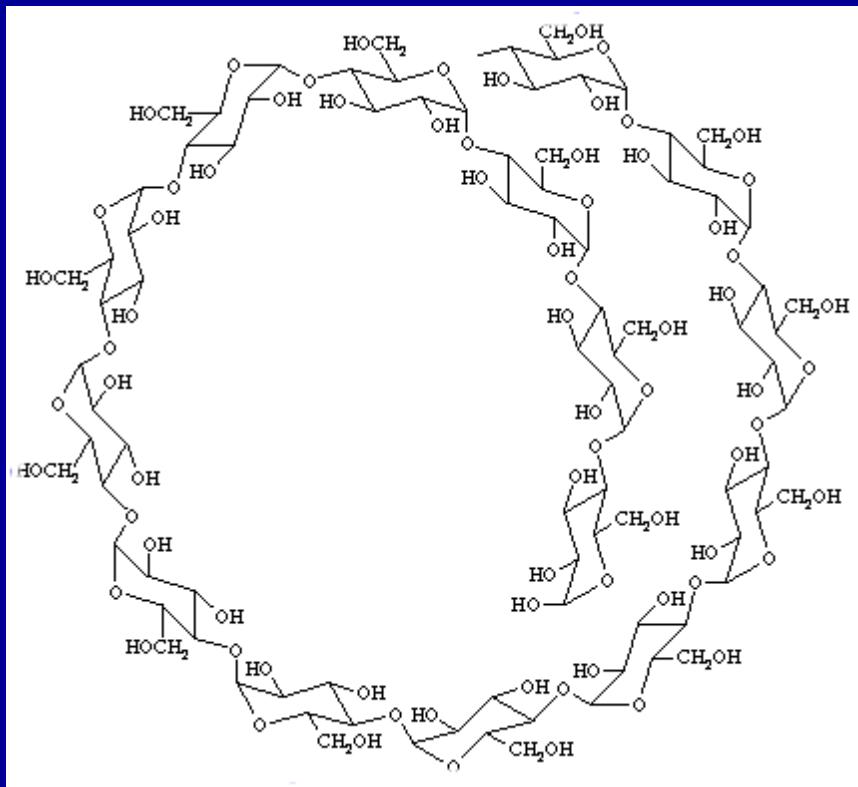
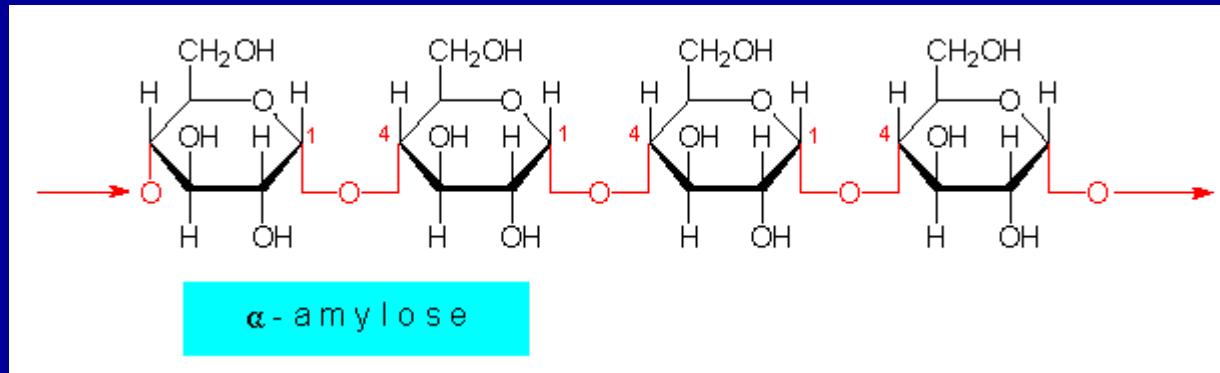


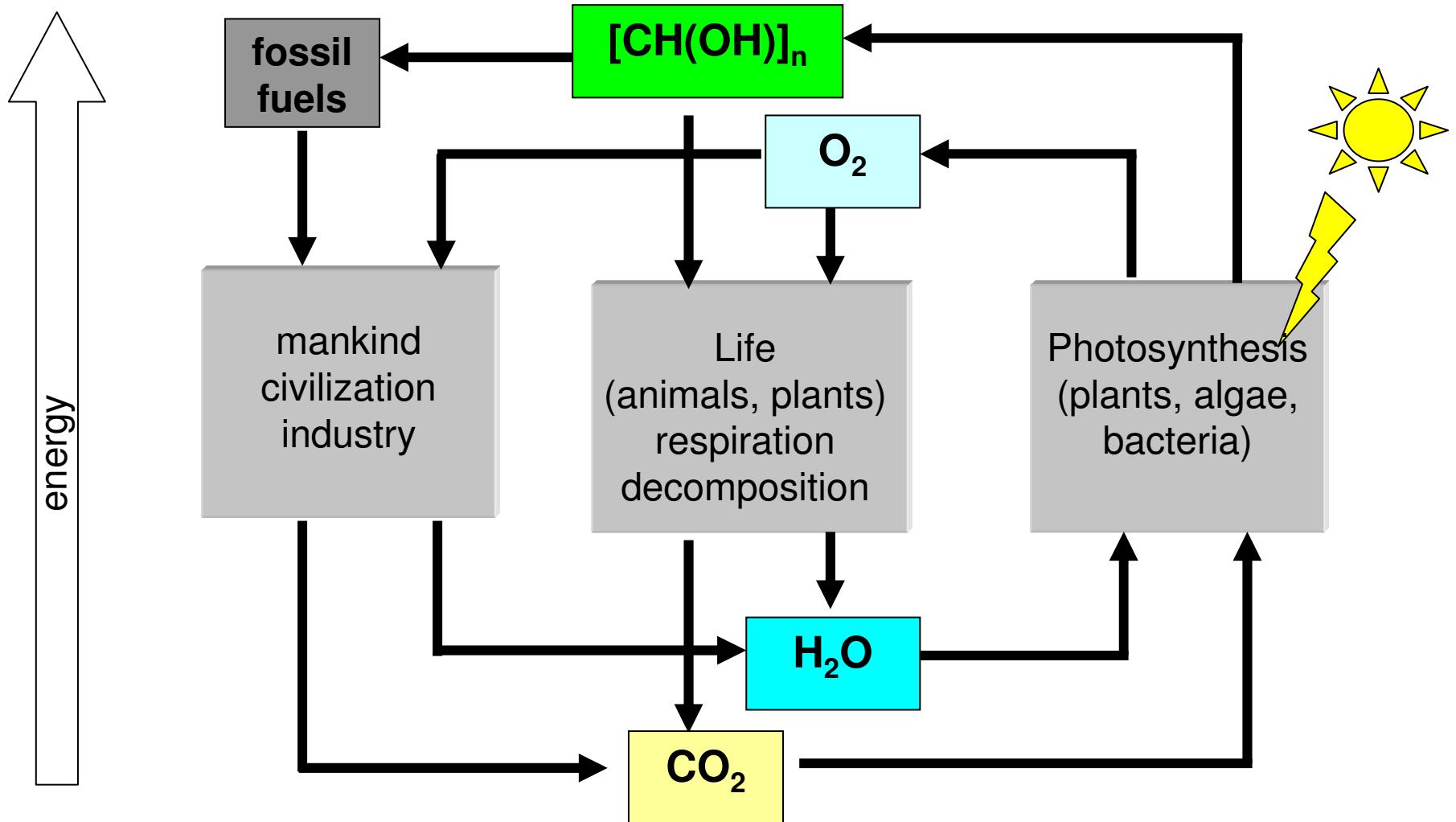
- usare la luce solare per ottenere combustibili
(composti chimici ad alto contenuto di energia)

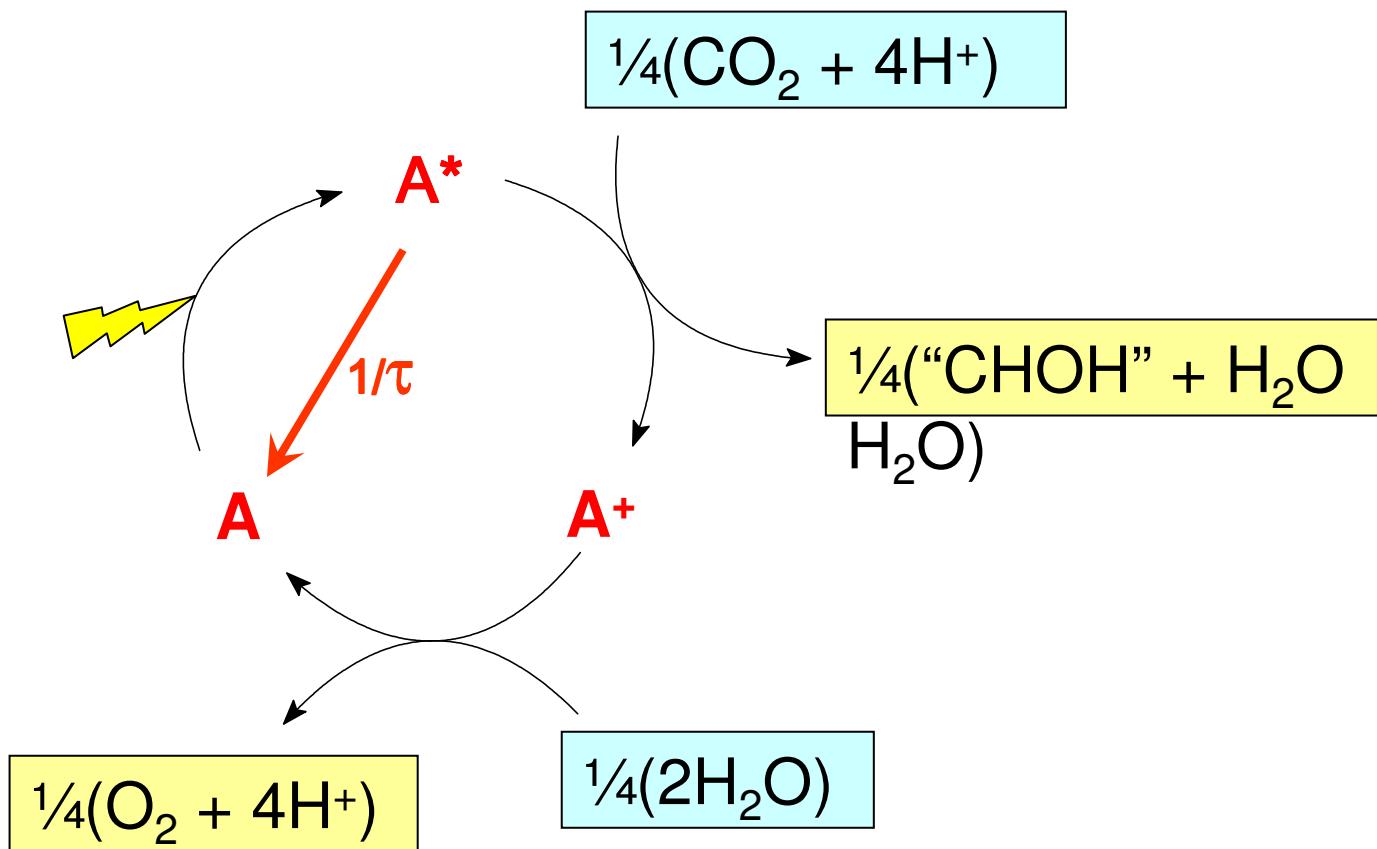
Fuel-generating Reactions			
reaction	n	$\Delta E^\circ(V)$	
$H_2O_{(l)} \rightarrow H_{2(g)} + \frac{1}{2} O_{2(g)}$	2	1.23	
$CO_{2(g)} + H_2O_{(l)} = "HCOH"_{(s)} + O_{2(g)}$	4	1.30	
$CO_{2(g)} + 2H_2O \rightarrow CH_3OH_{(l)} + (3/2)O_{2(g)}$	6	1.21	
$CO_{2(g)} + 2H_2O \rightarrow CH_4_{(g)} + 2O_{2(g)}$	8	1.06	
$N_{2(g)} + 3H_2O \rightarrow 2NH_3_{(g)} + (3/2)O_{2(g)}$	6	1.17	

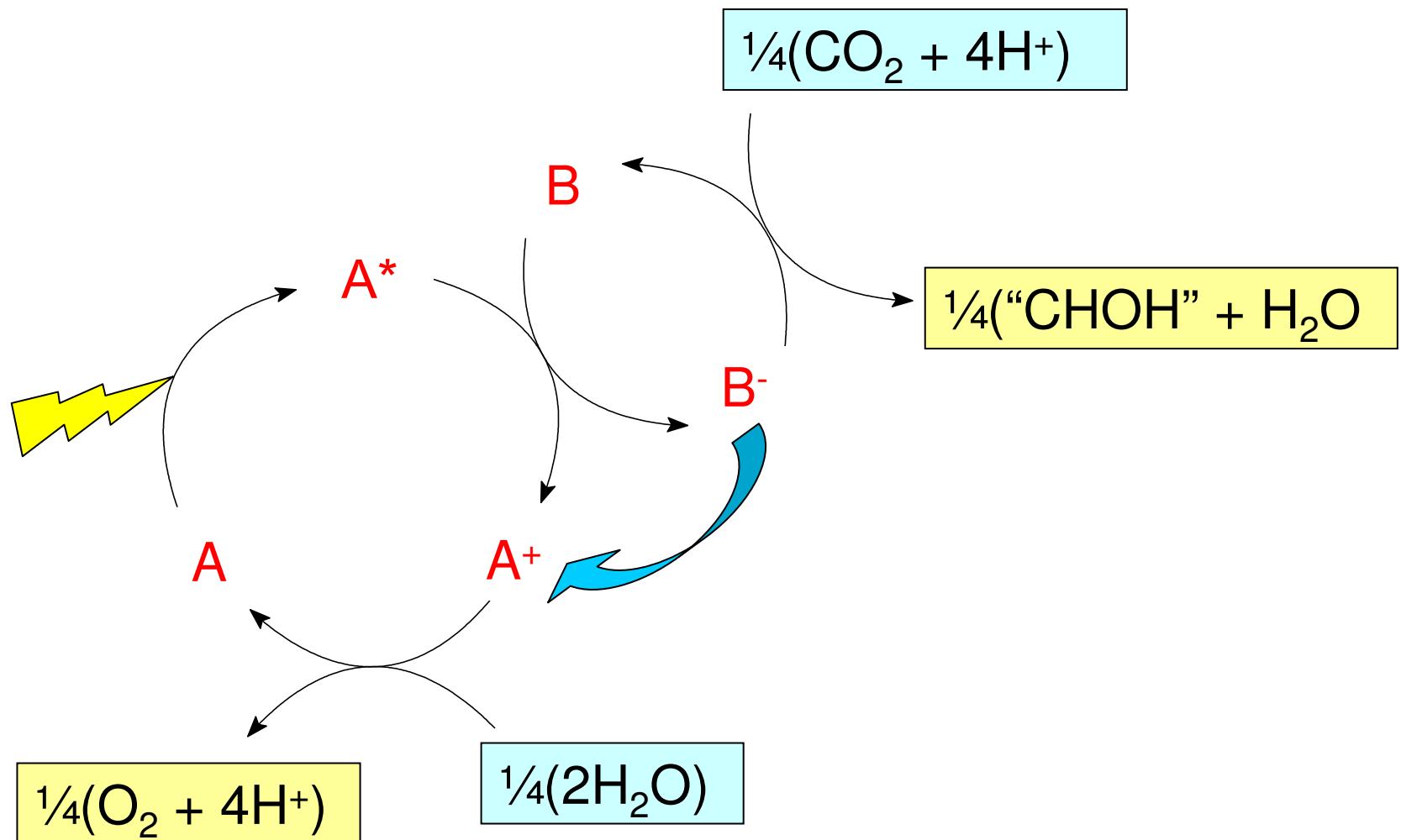
Il processo fotosintetico









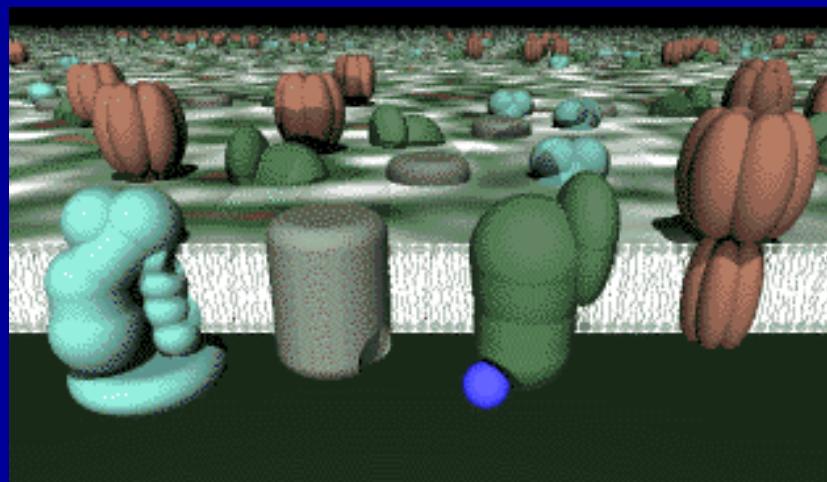
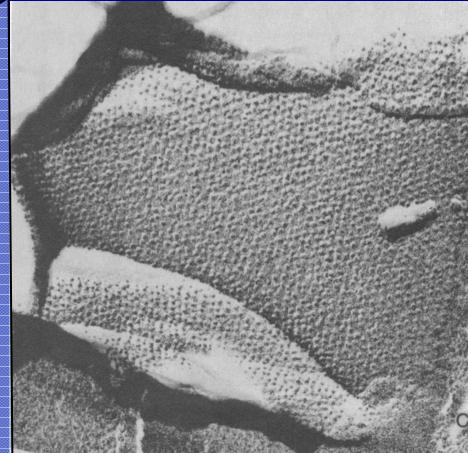




Examples of photosynthetic organisms:

- leaves from higher plants
- photosynthetic purple bacteria
- cyanobacteria

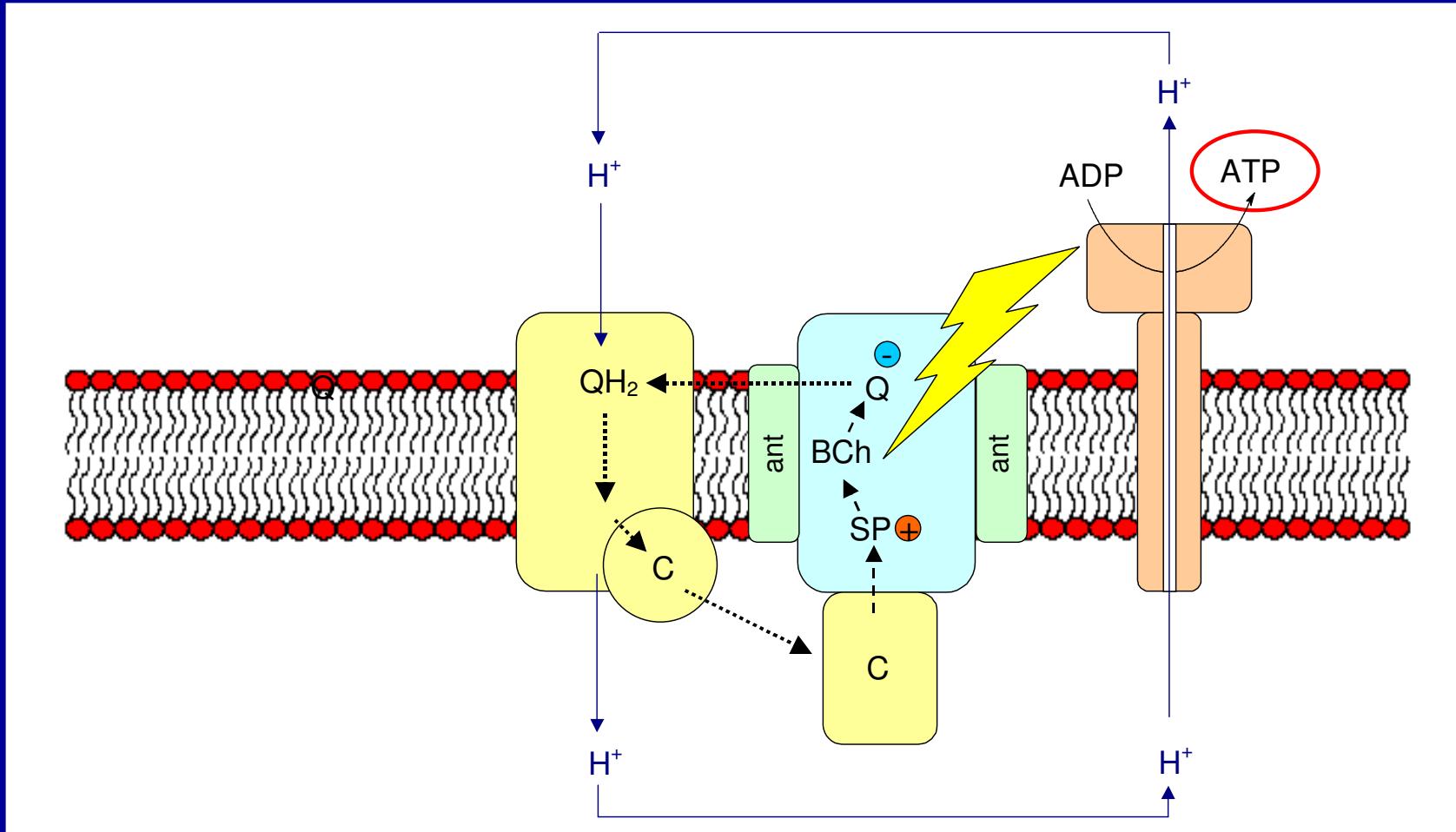
Rodopseudomonas viridis photosynthetic membrane (SEM)



(cartoon)

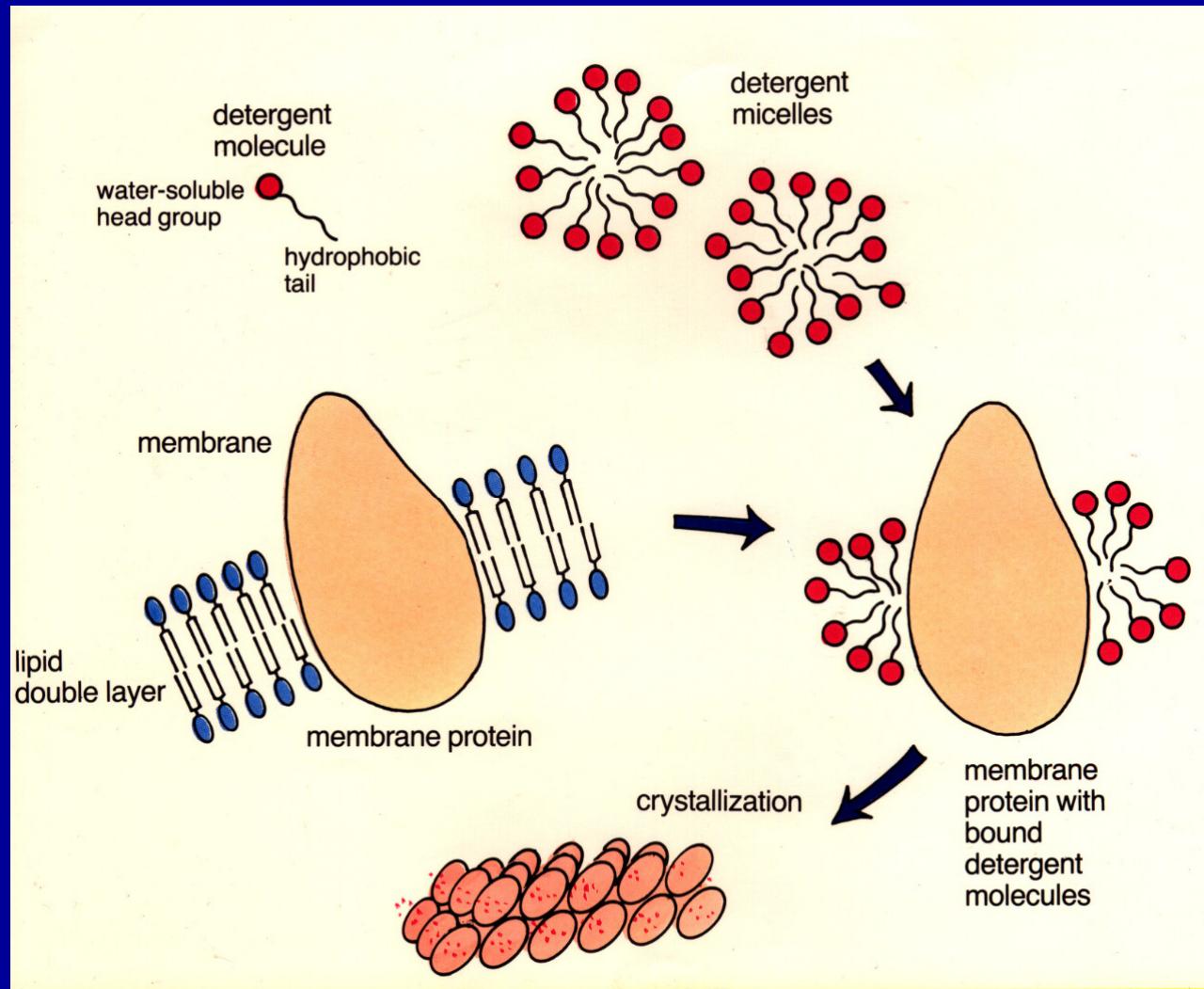
Transmembrane protein complexes

- reaction centers, - light-harvesting (antenna) systems, ATP-ases,

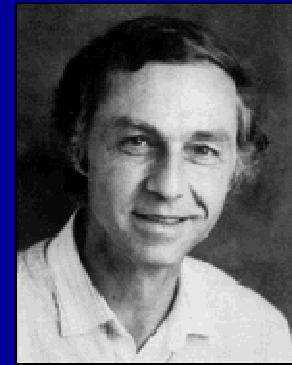
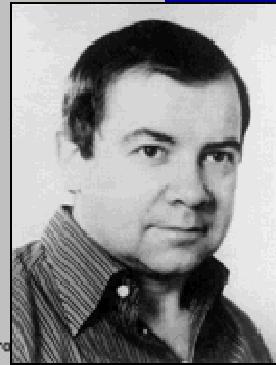
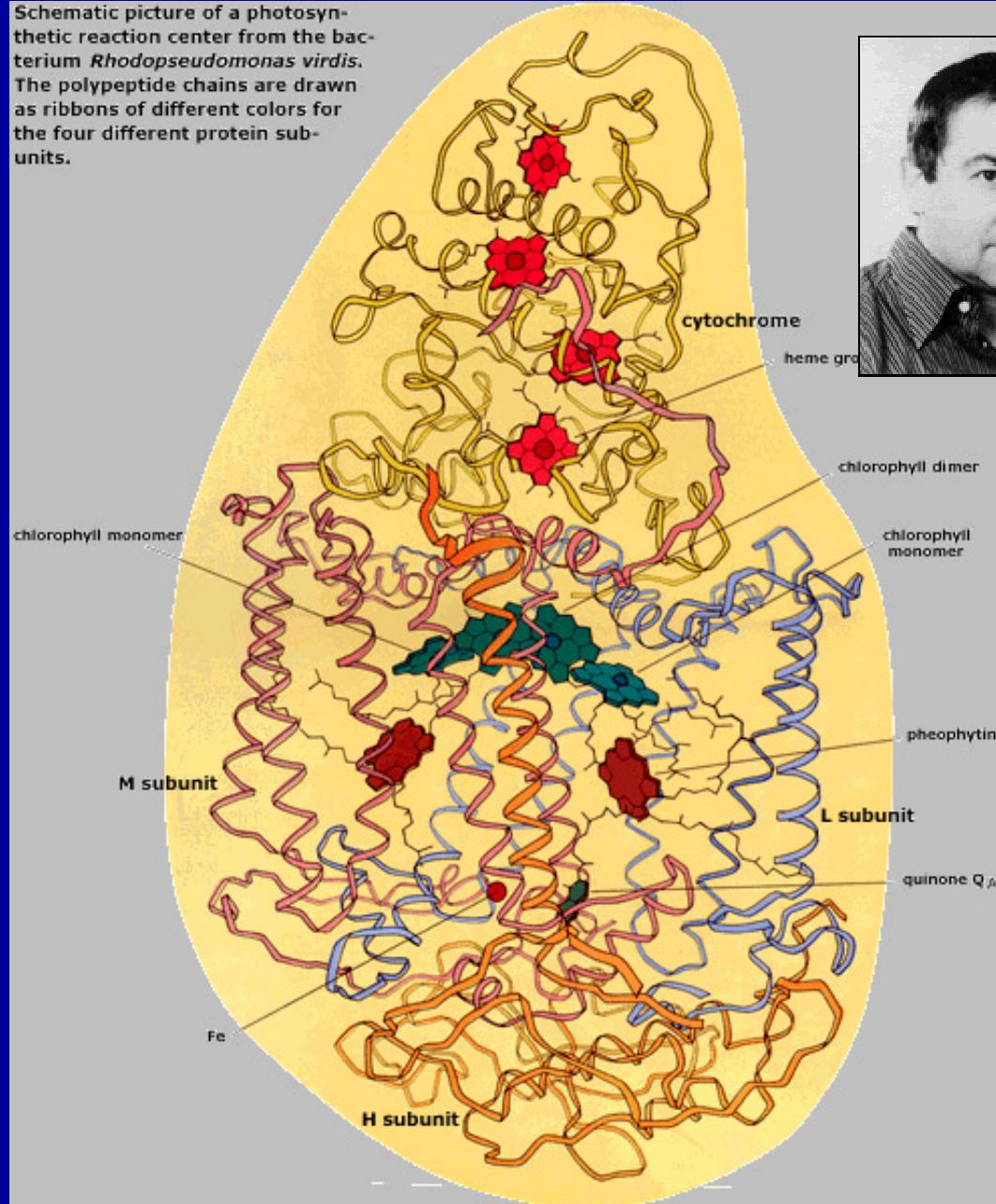


>1988 rapid progress in structural knowledge
(crystallization + diffraction)

Extraction and Crystallization of Transmembrane Protein Complexes



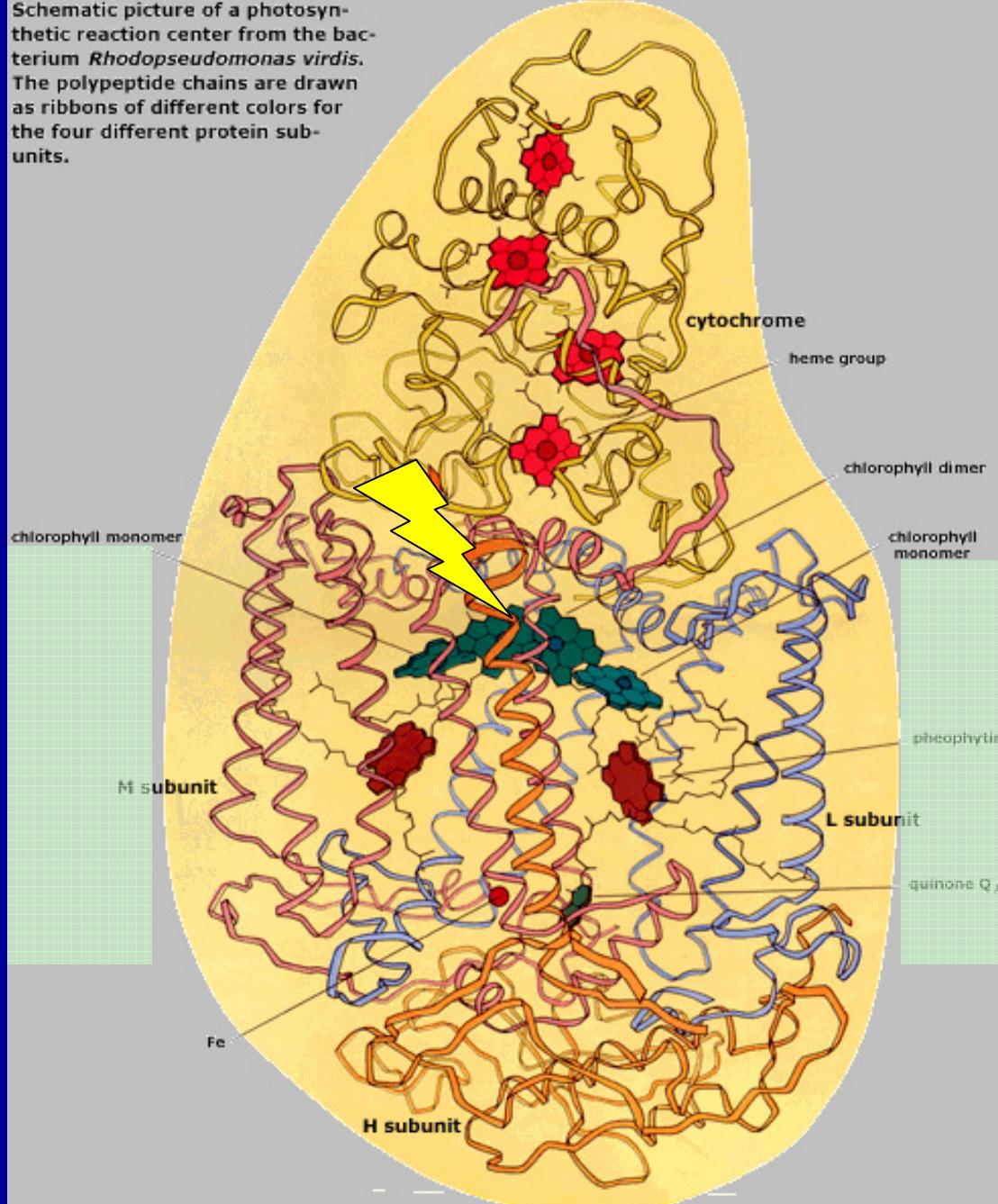
Schematic picture of a photosynthetic reaction center from the bacterium *Rhodopseudomonas viridis*. The polypeptide chains are drawn as ribbons of different colors for the four different protein sub-units.



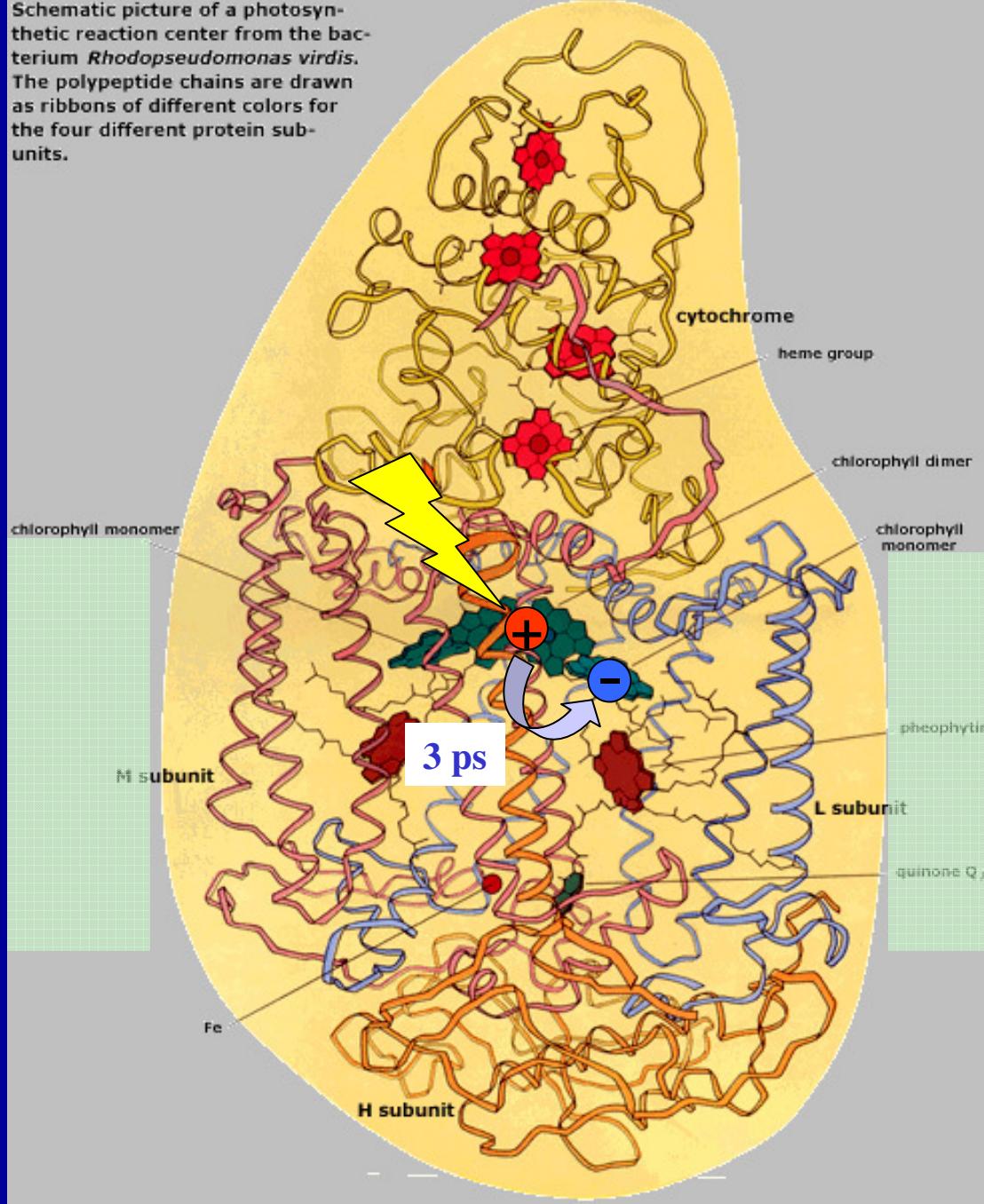
J. Diesenhofer,
R. Huber,
H. Michel

Nobel Prize in Chemistry 1998

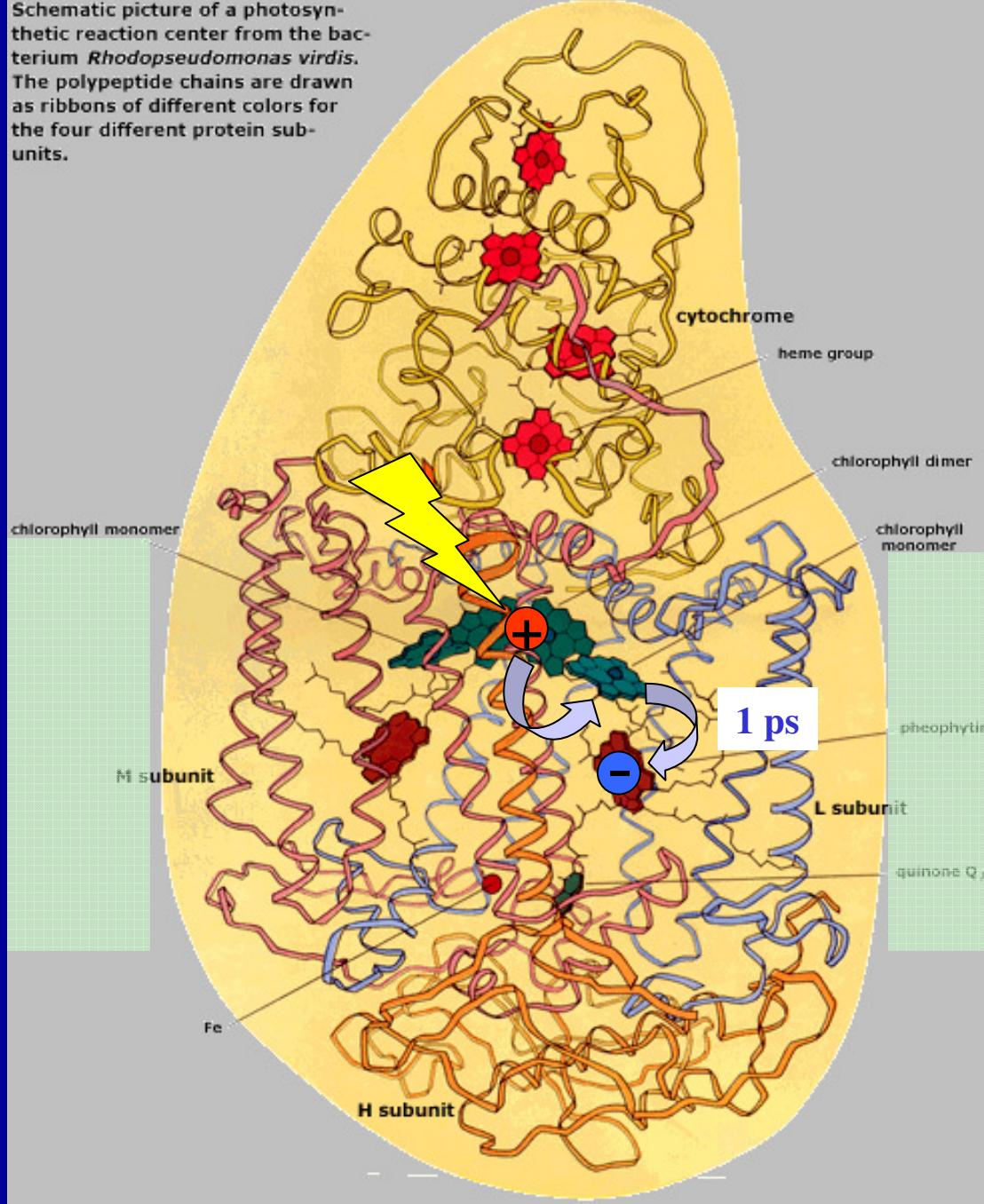
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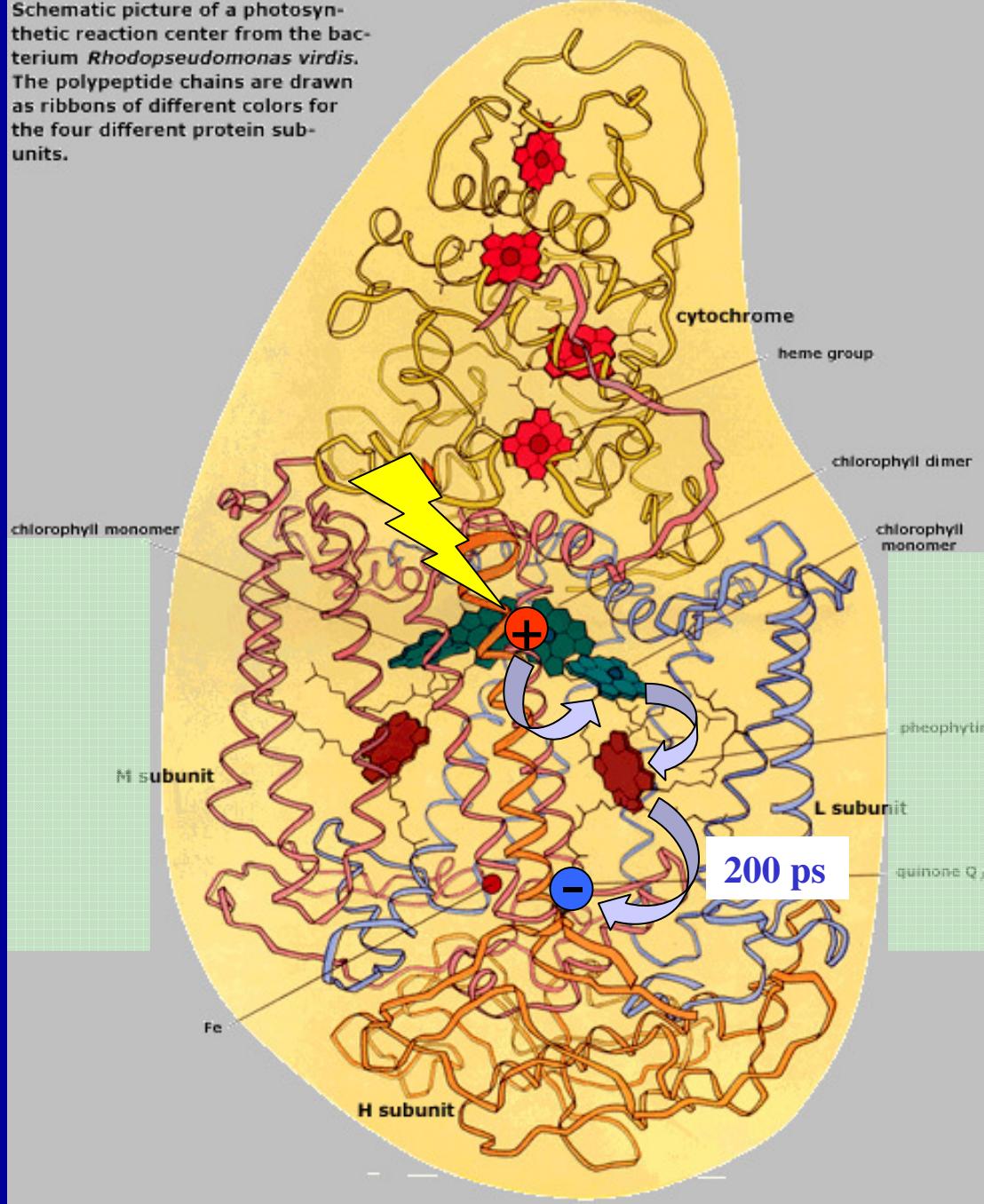
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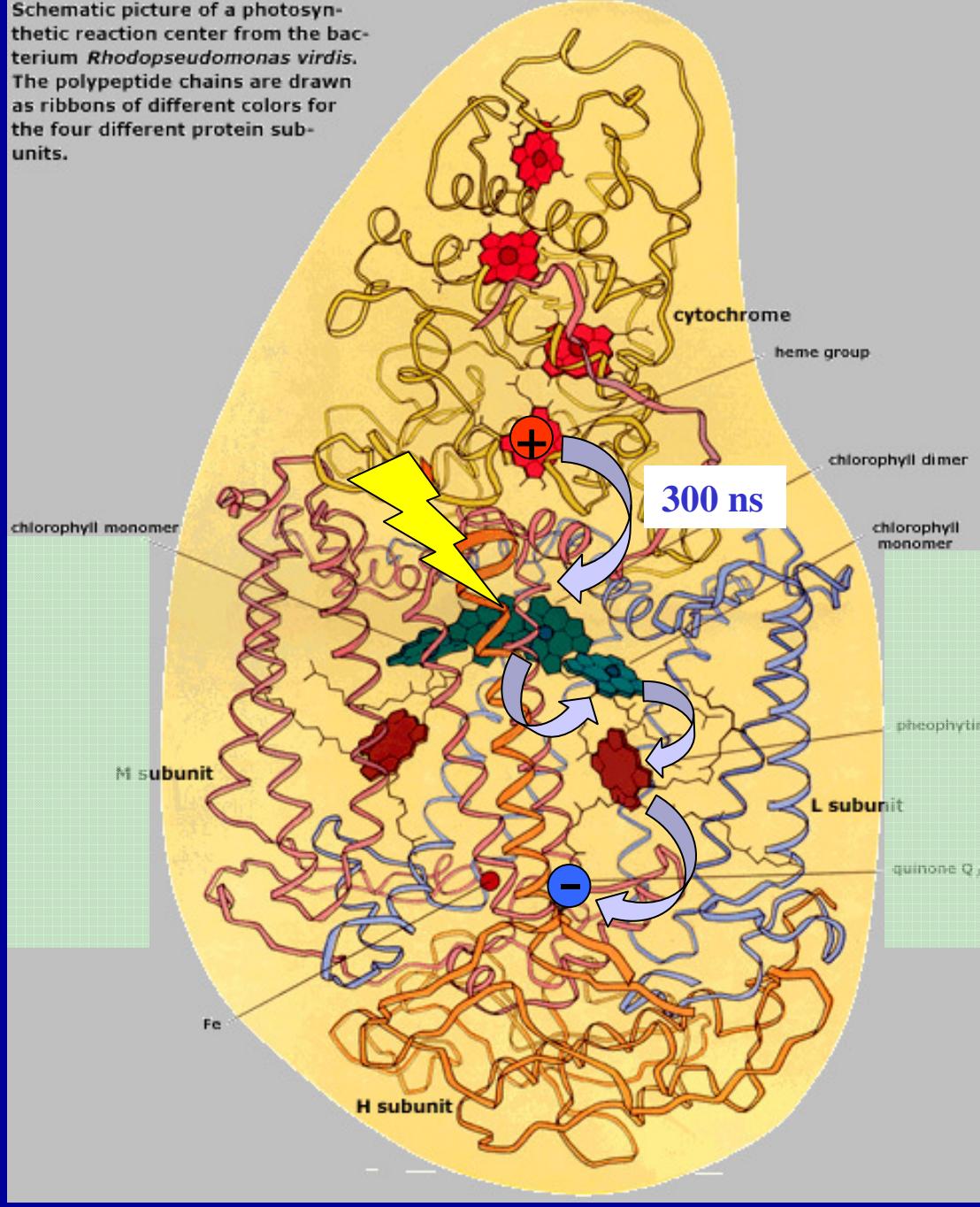
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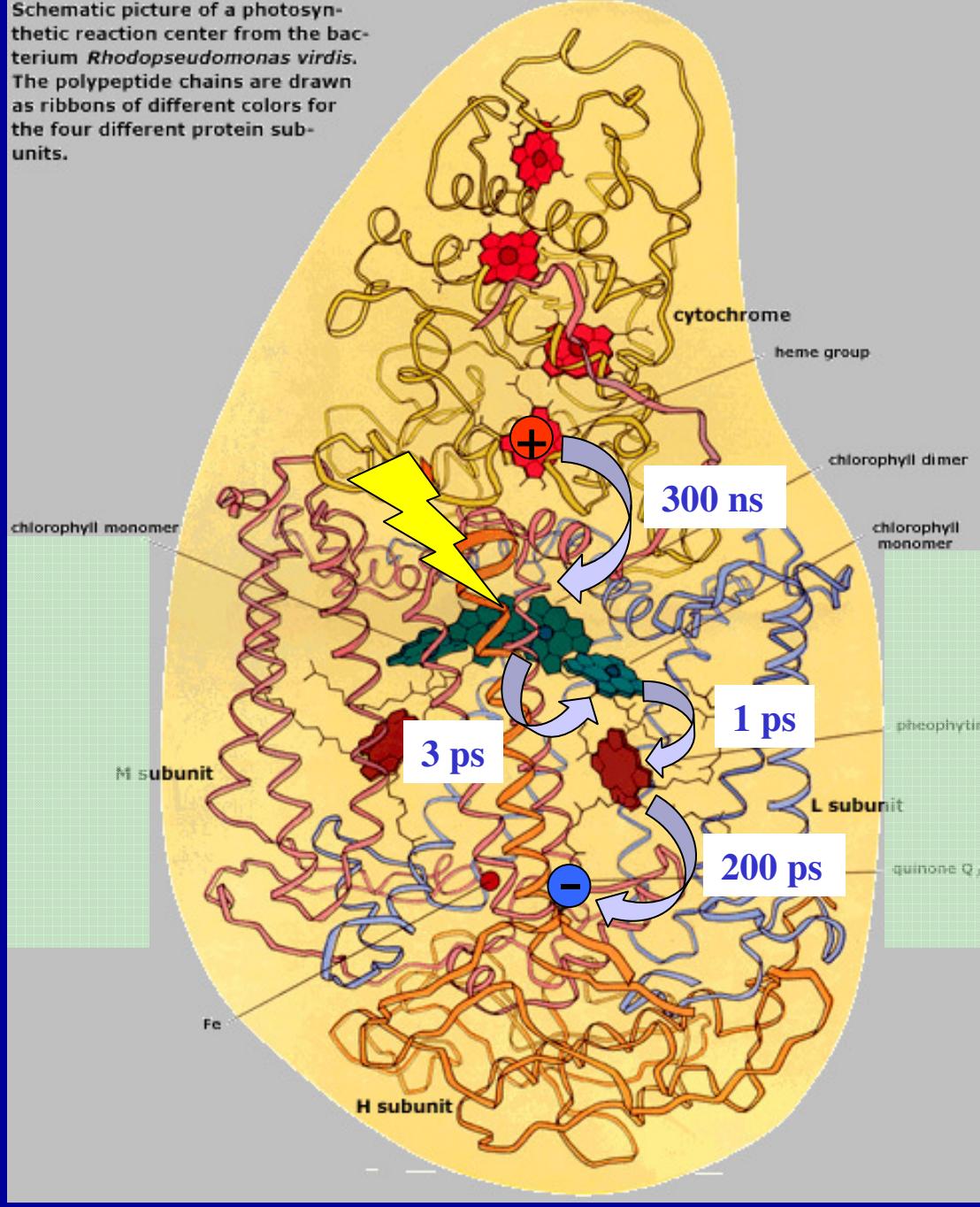
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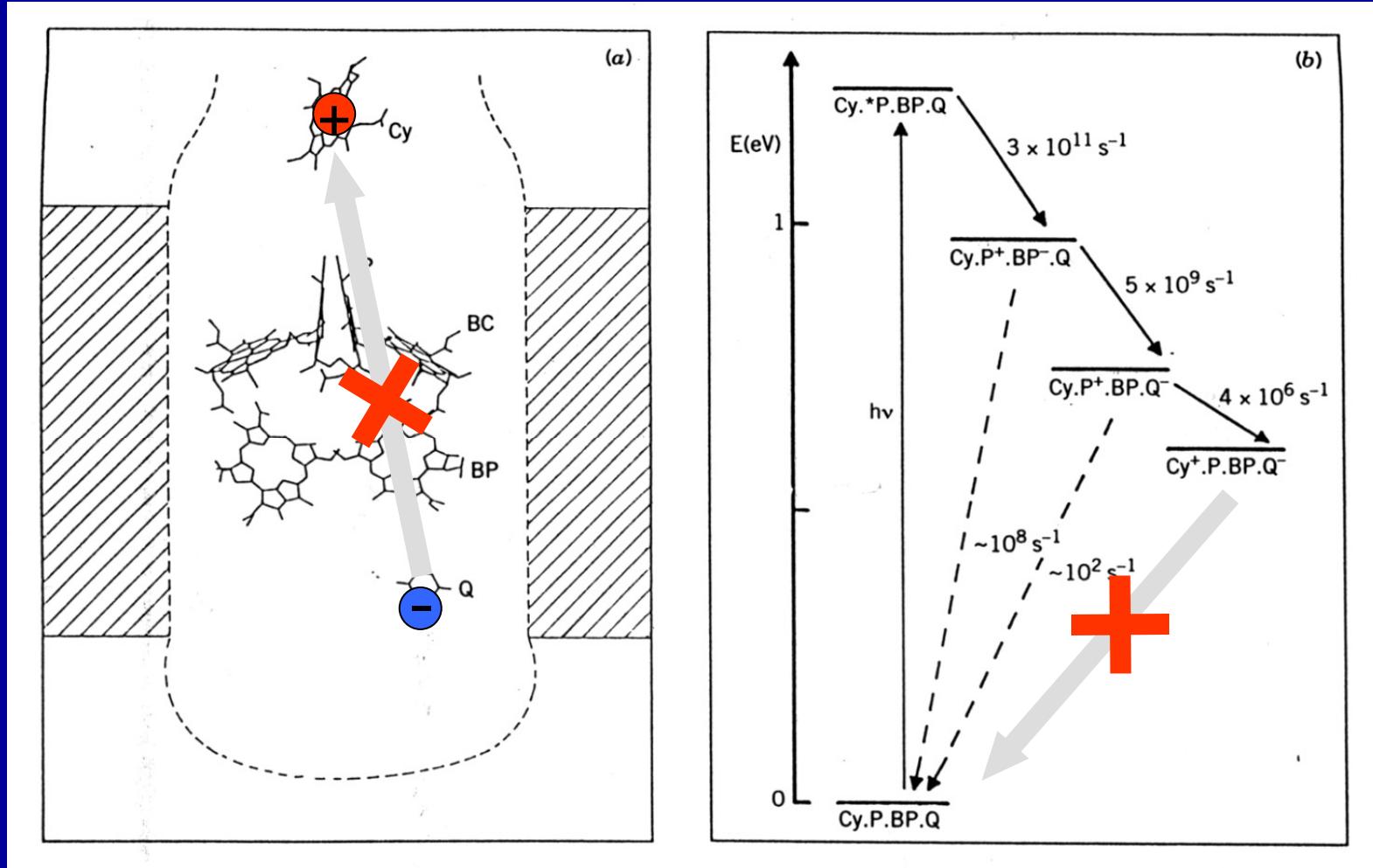


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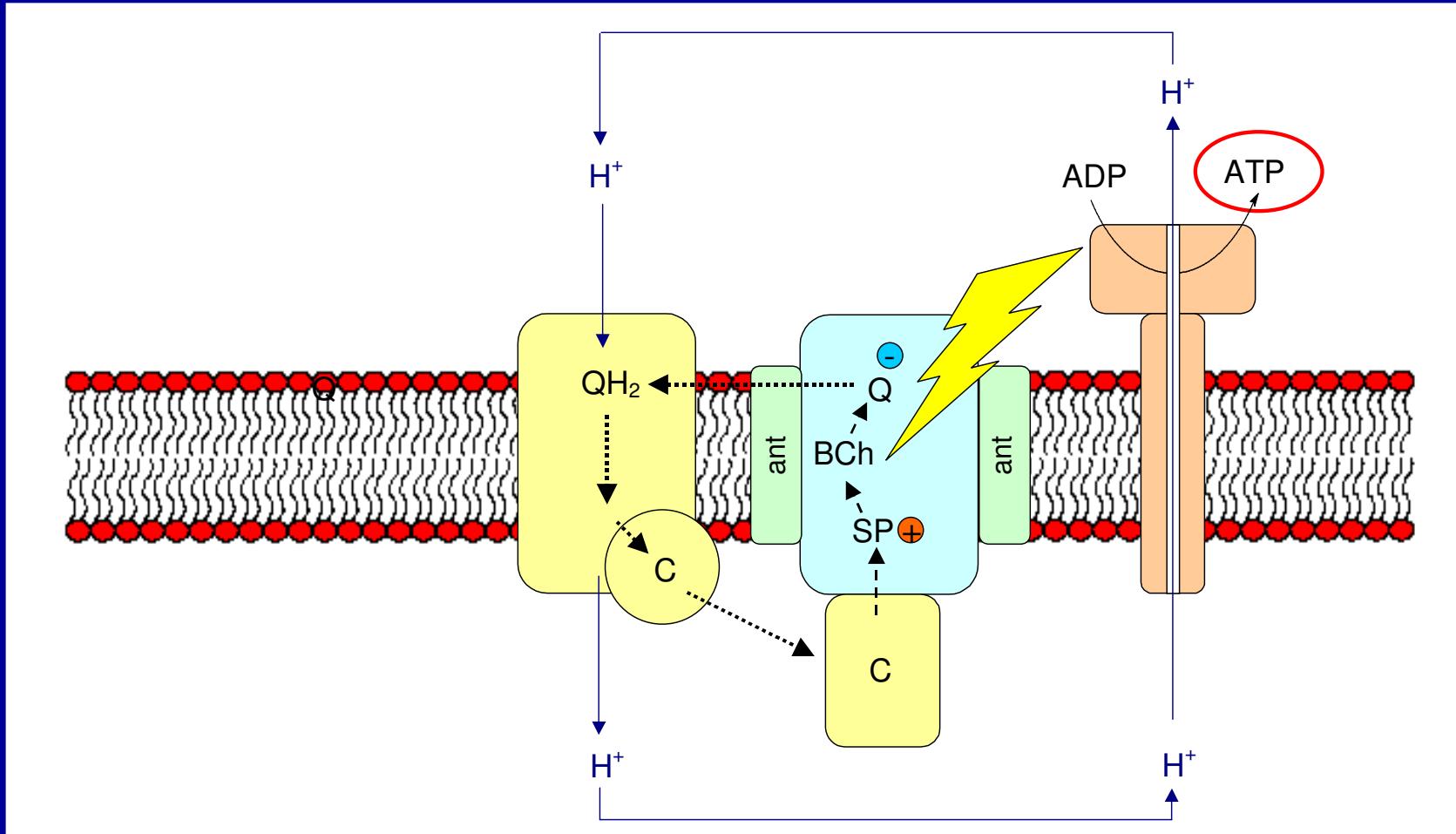
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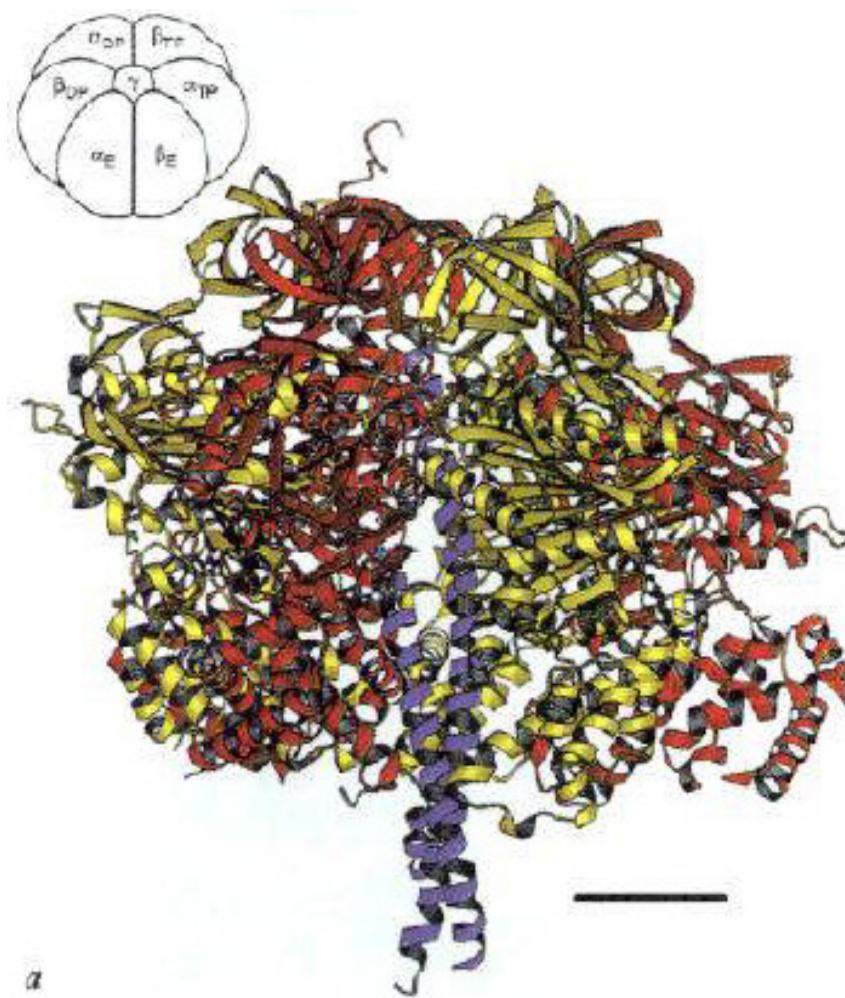
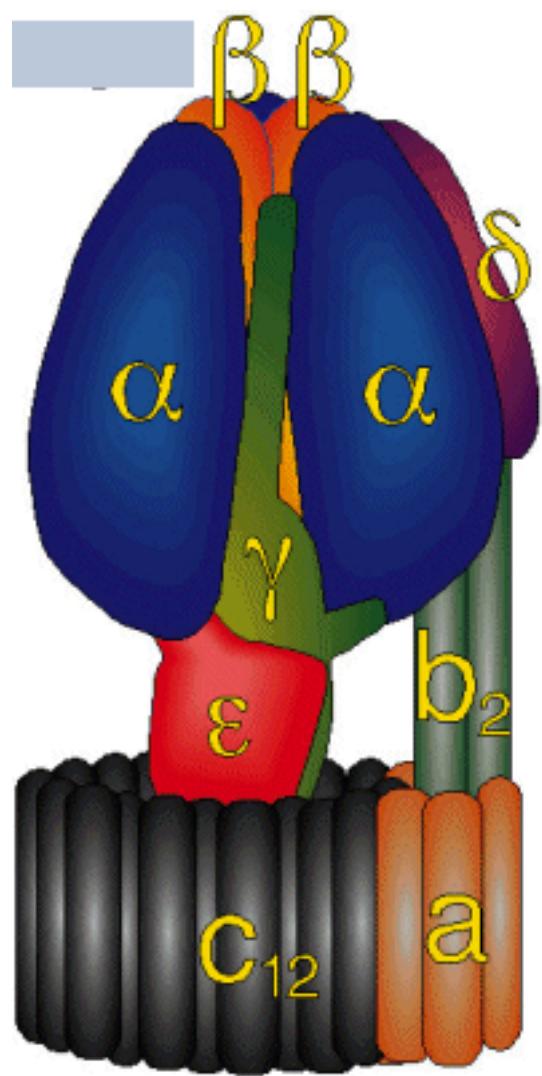




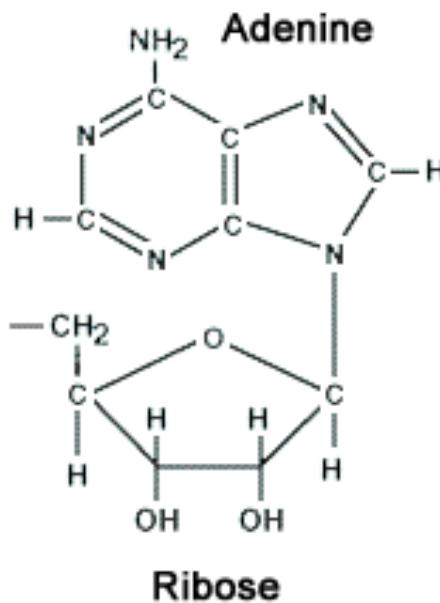
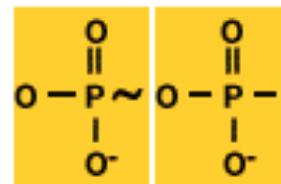
Transmembrane protein complexes

- reaction centers, - light-harvesting (antenna) systems, ATP-ases,

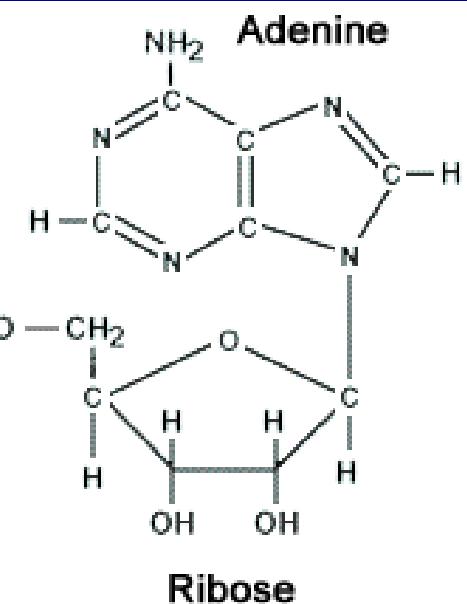
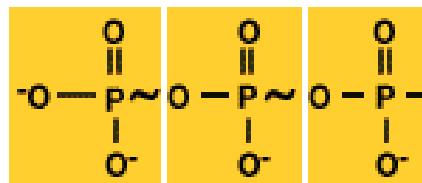




2 Phosphate Groups

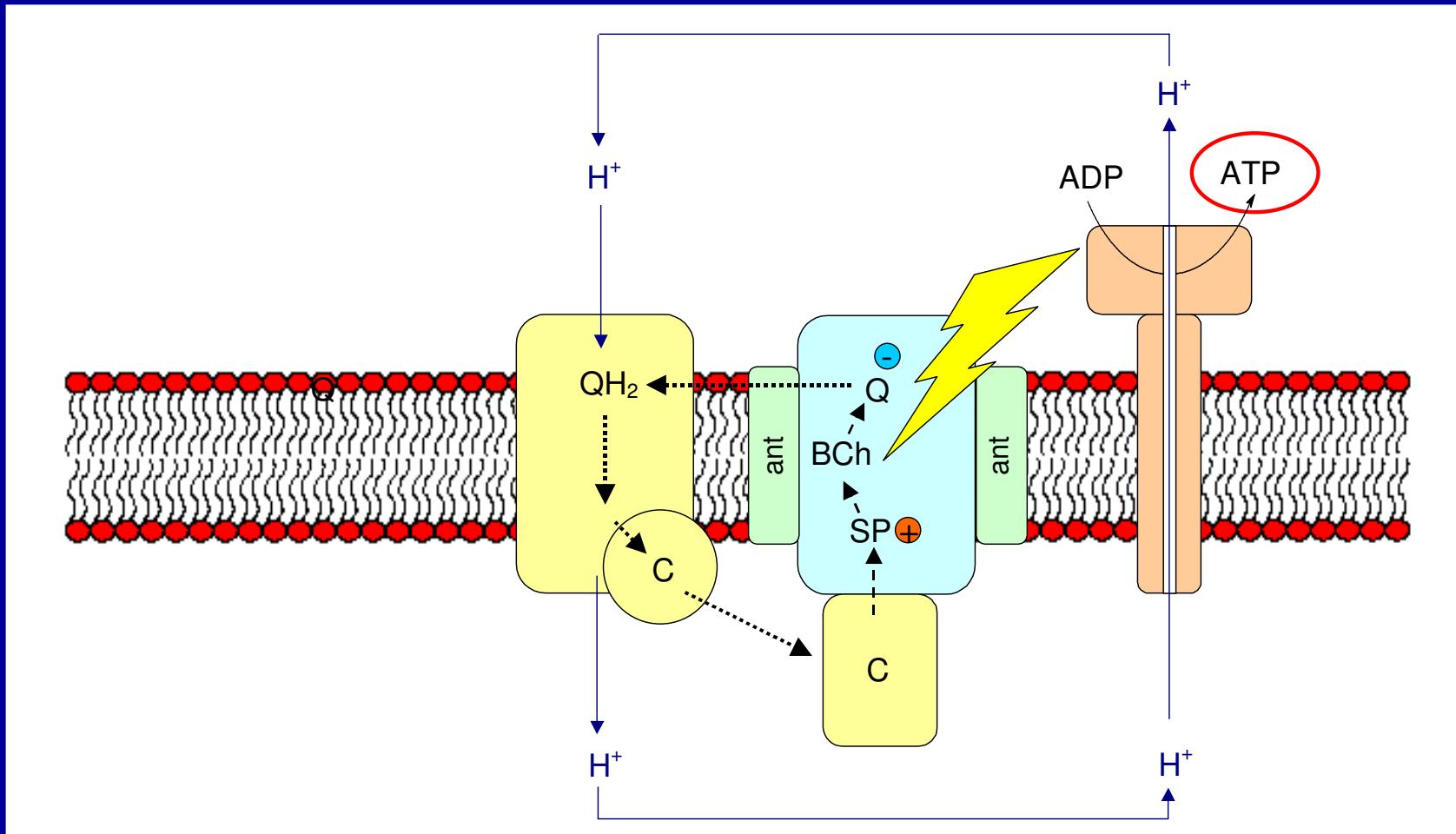


3 Phosphate Groups



Transmembrane protein complexes

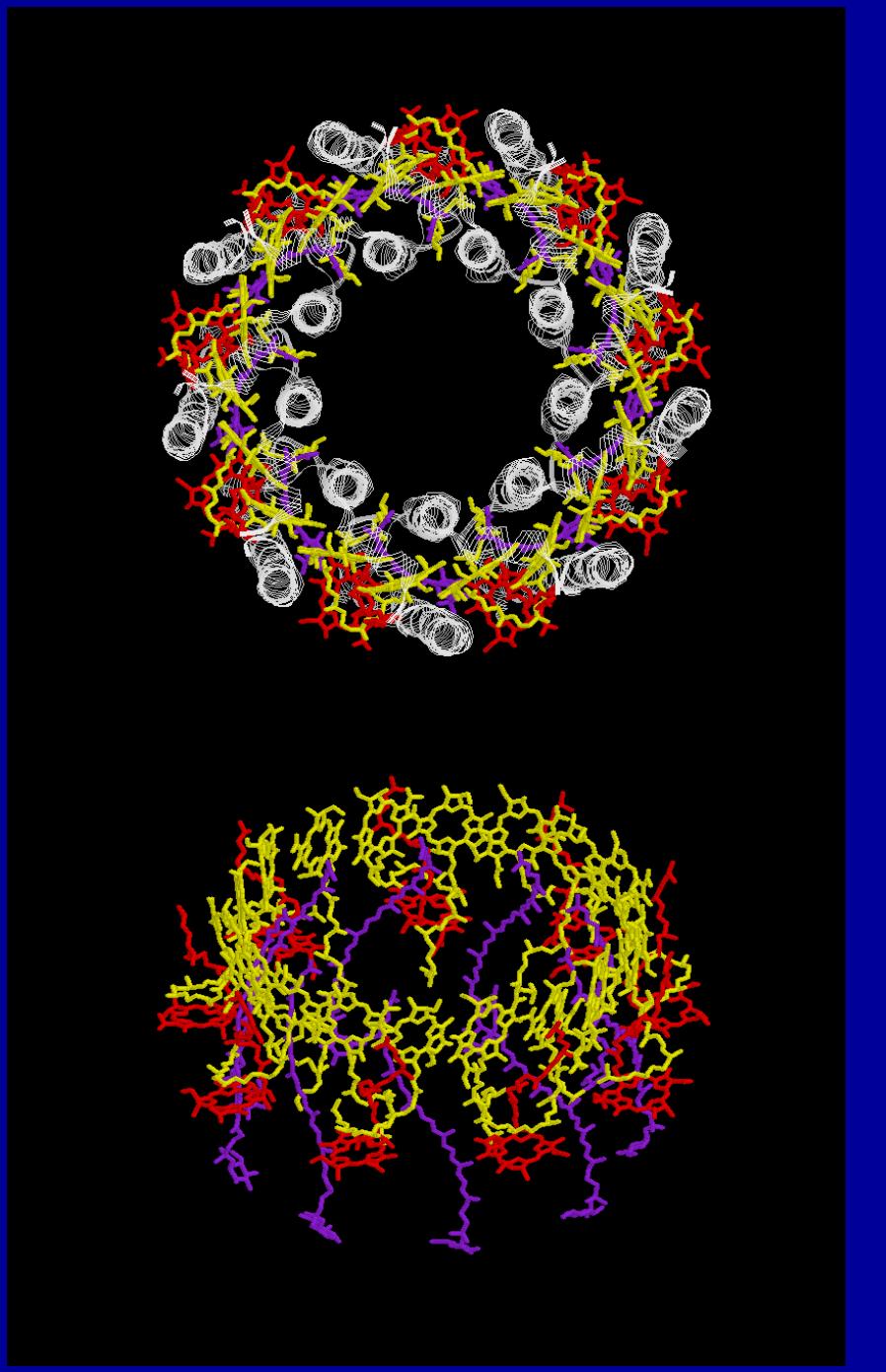
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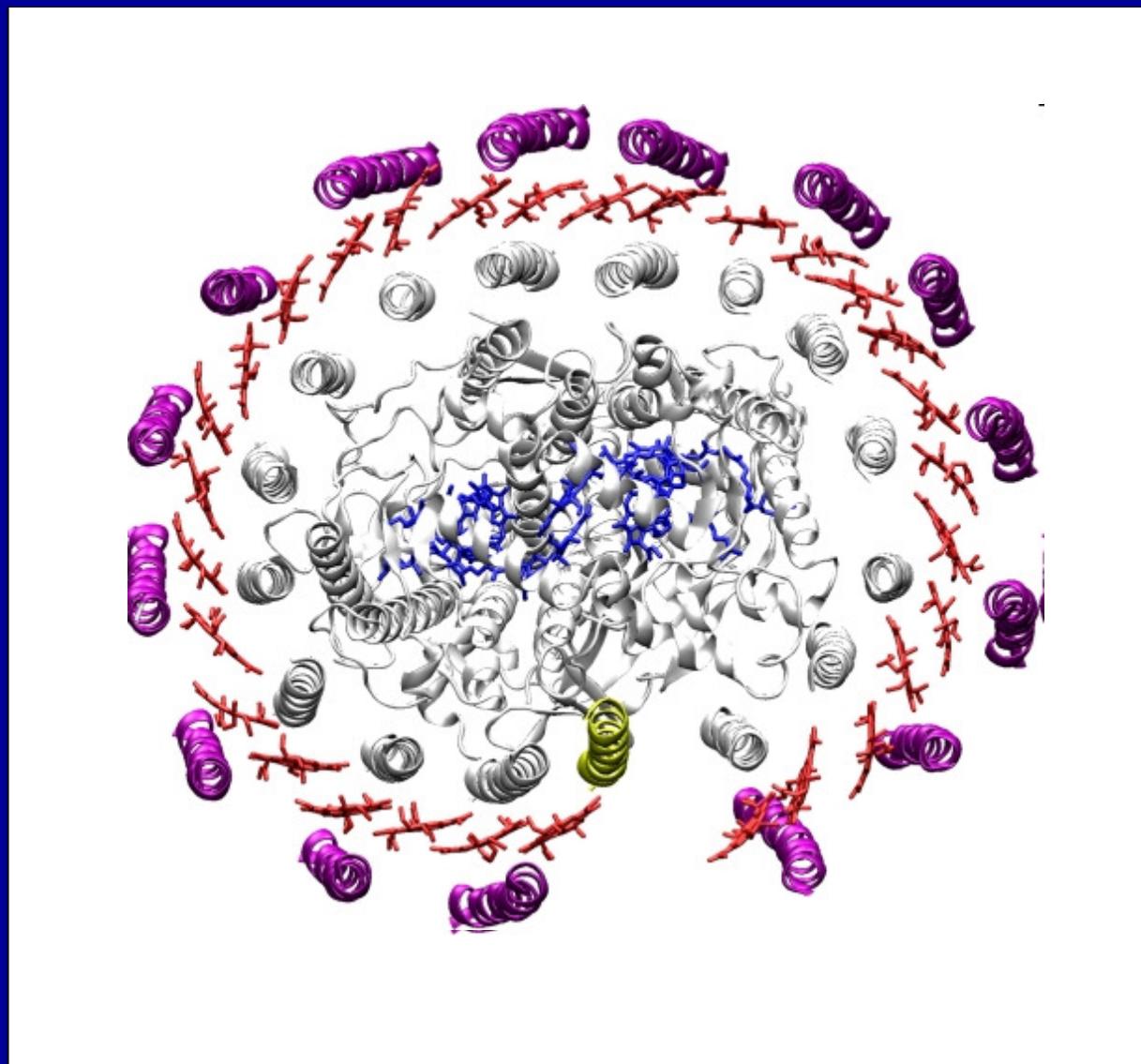
>1988 rapid progress in structural knowledge
(crystallization + diffraction)

LH-II Light Harvesting Complex

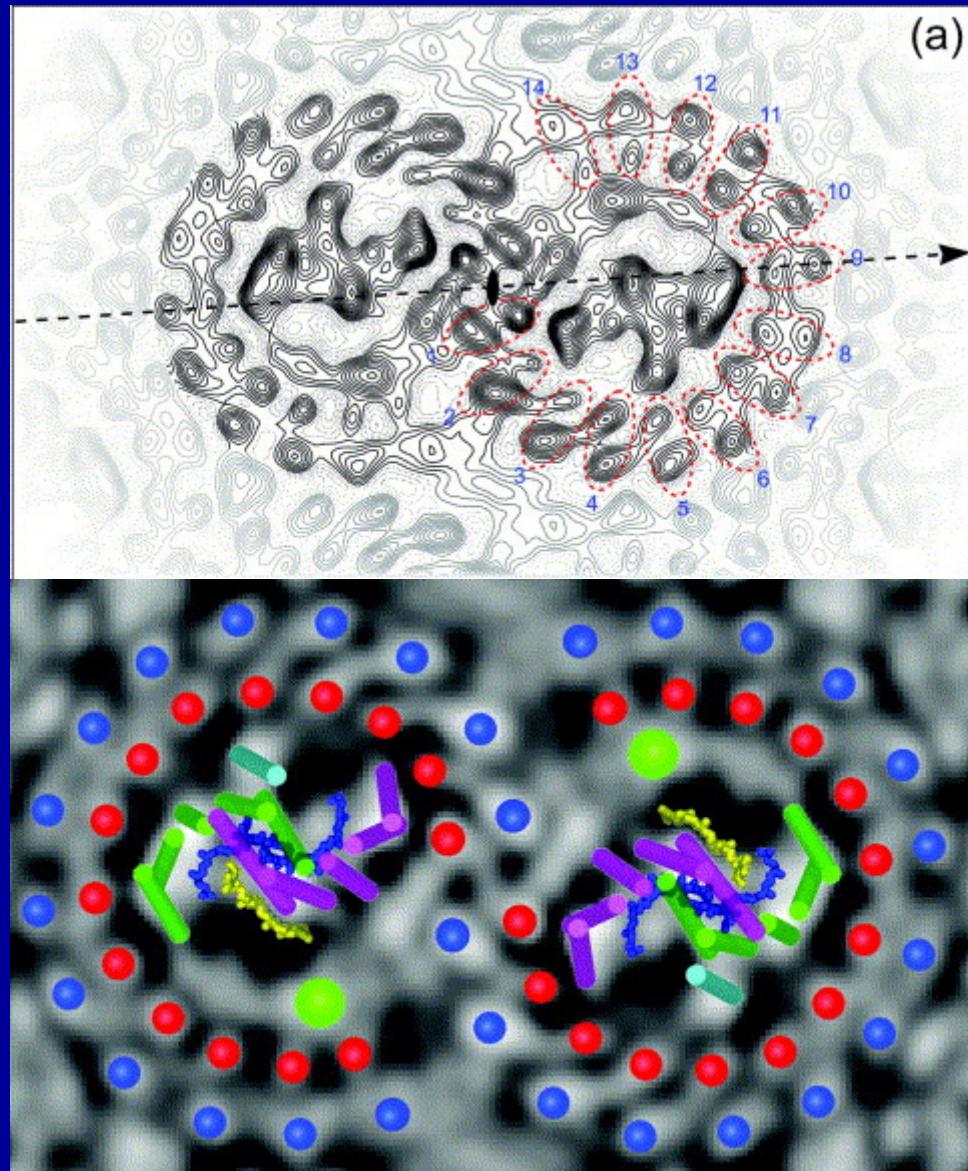
G. McDermott, S. M. Prince, A. A. Freer,
A. M. Hawthornthwaite-Lawless, M. Z.
Papiz, R. J. Cogdell, , N. W. Isaacs,
Nature **1995**, 374, 517.

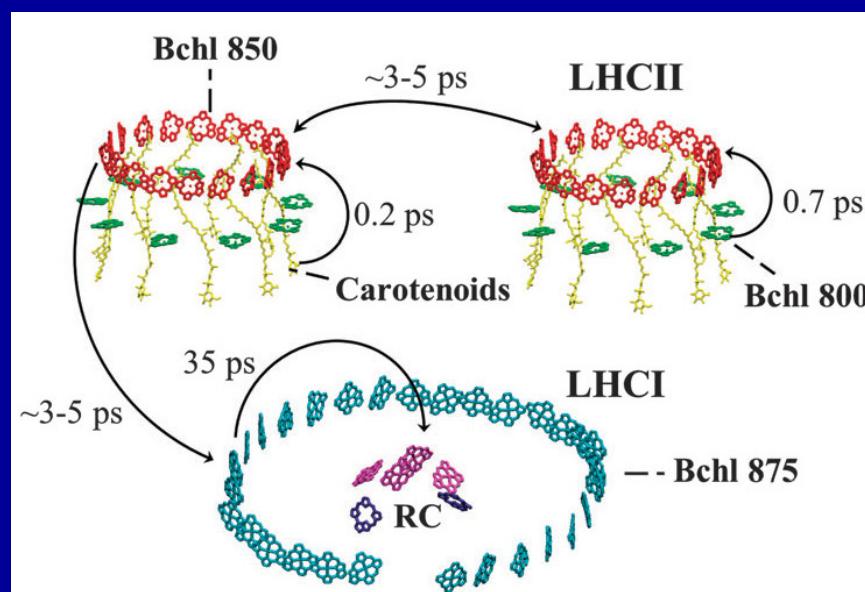
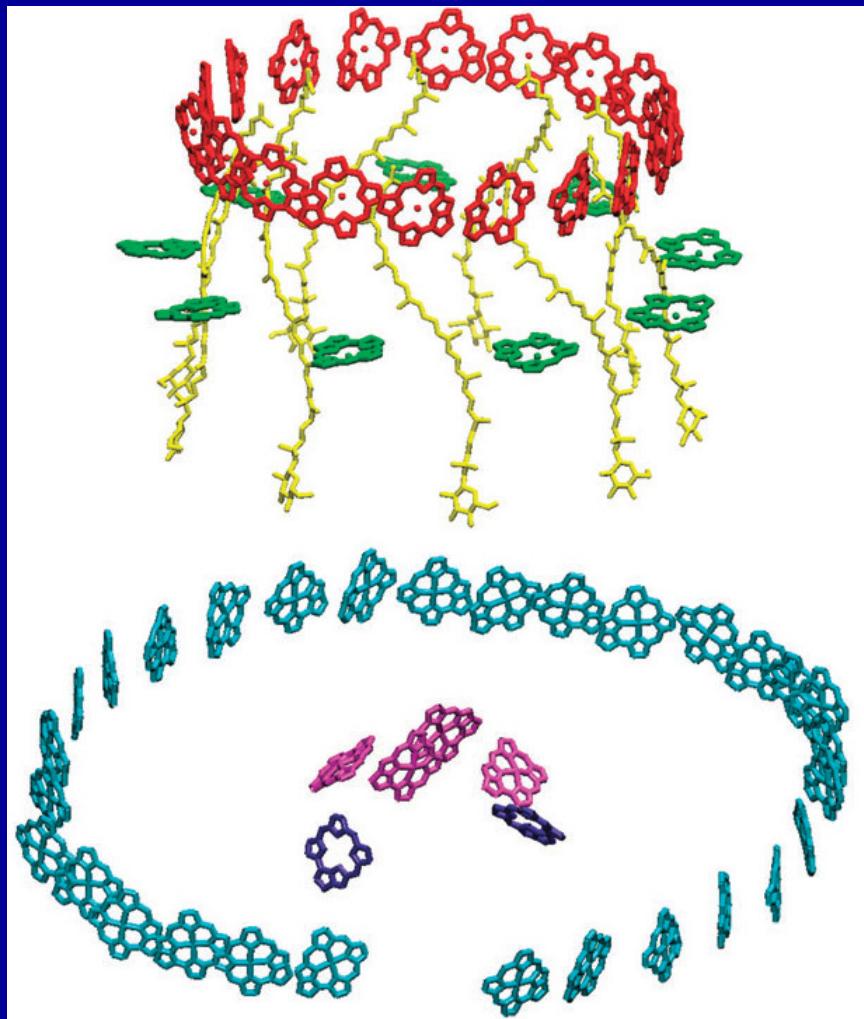


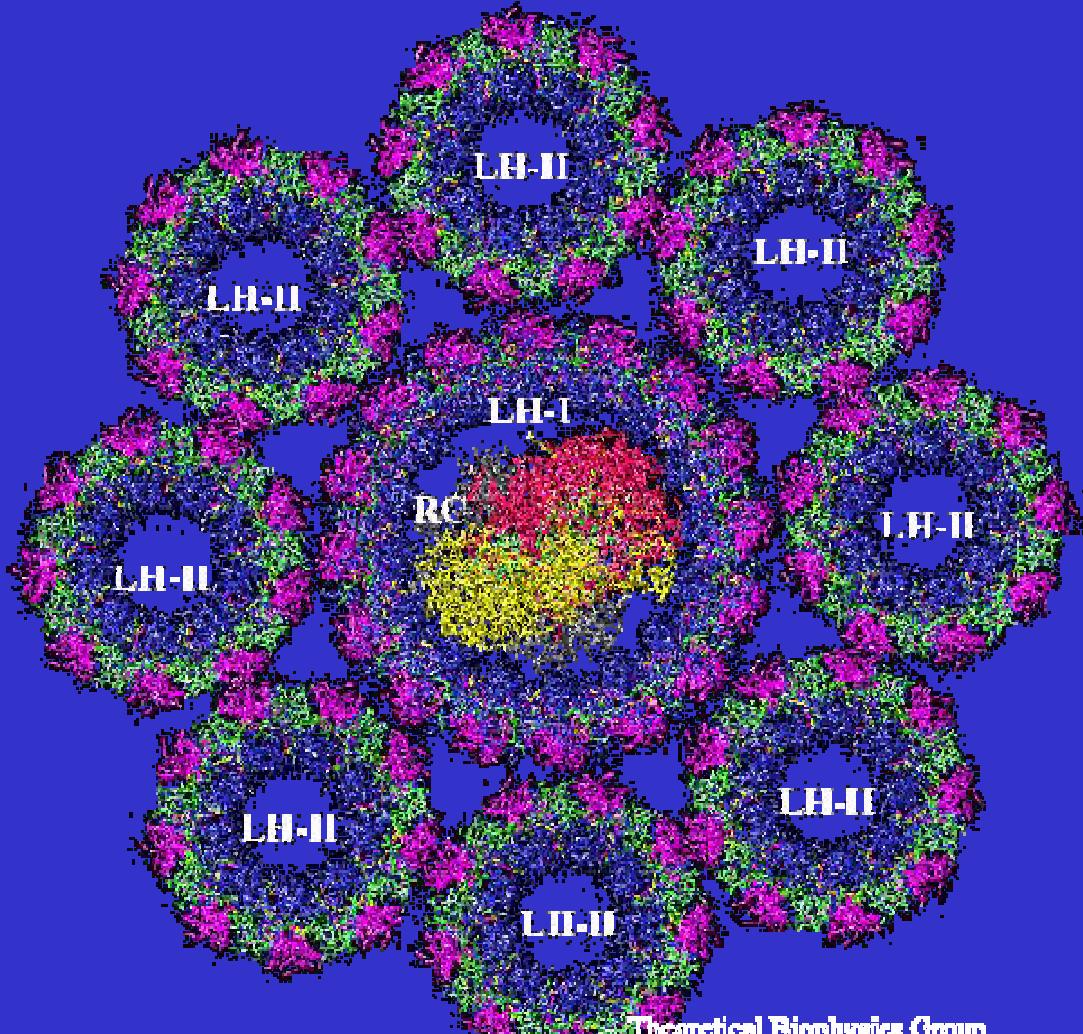
LH-I - Reaction Center Complex



Structure of LH-I - Reaction Center Dimeric Complex

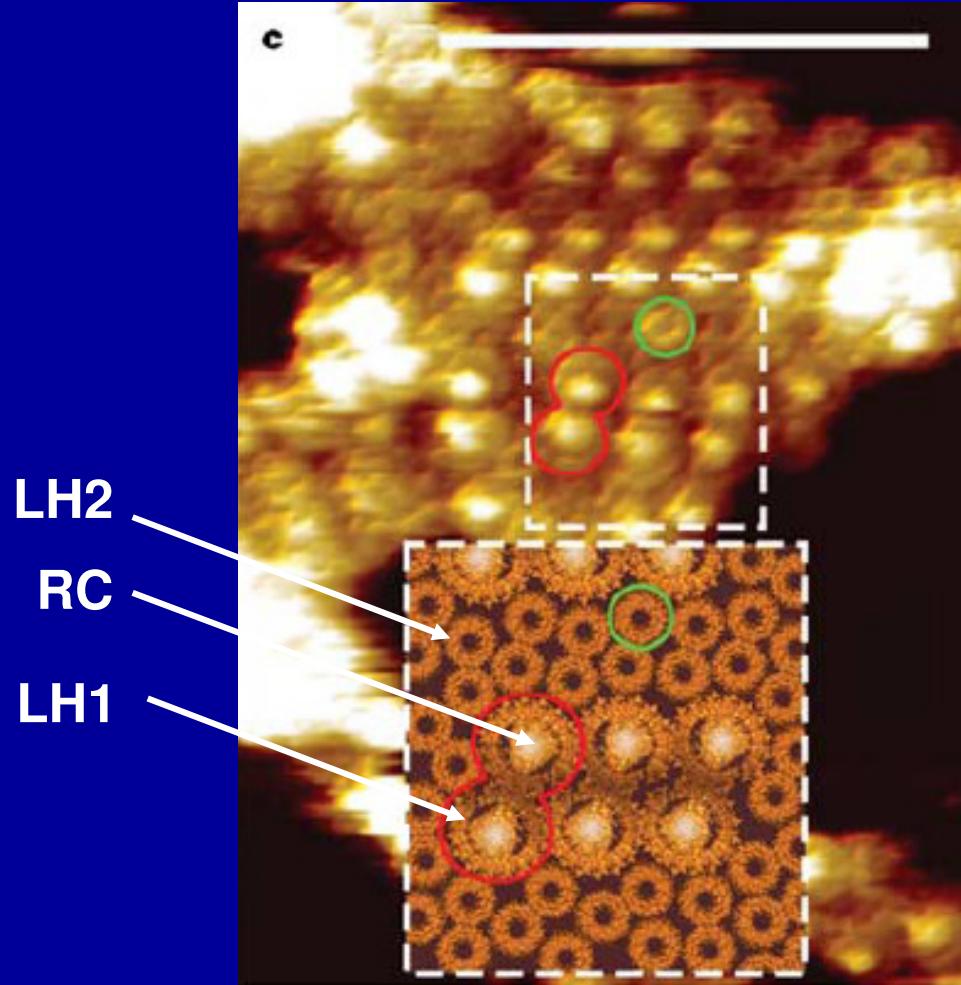






Theoretical Biophysics Group
Beckman Institute
University of Illinois at Urbana-Champaign

AFM Image of Native Photosynthetic Membrane (*Rhodobacter sphaeroides*)



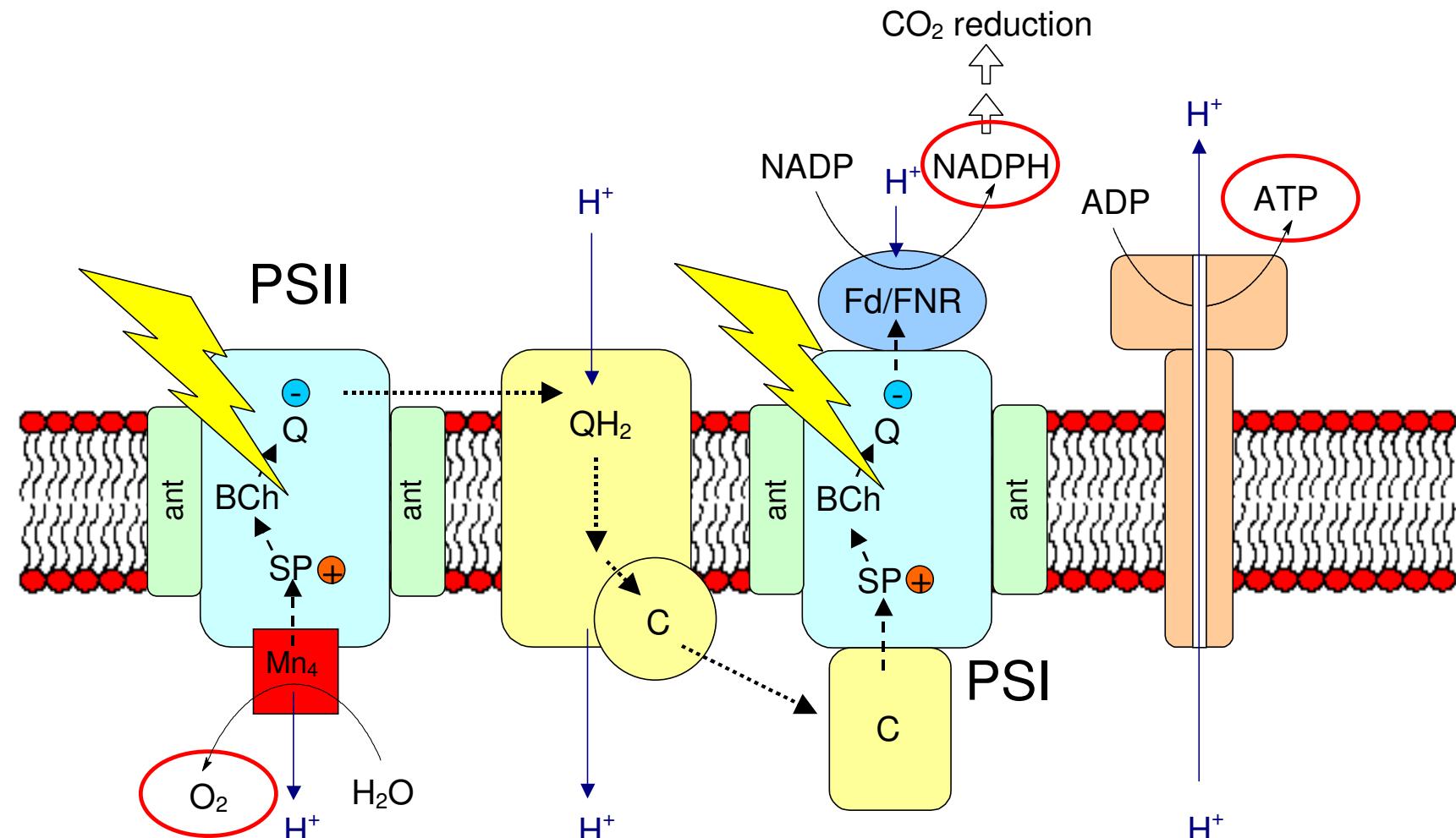
S. Bahatyrova, R. N. Frese, C. A. Siebert, J. D. Olsen, K. O. van der Werf, R. van Grondelle,
R. A. Niederman, P. A. Bullough, C. Otto, C. N. Hunter, *Nature* 2004, 430, 1058-1062



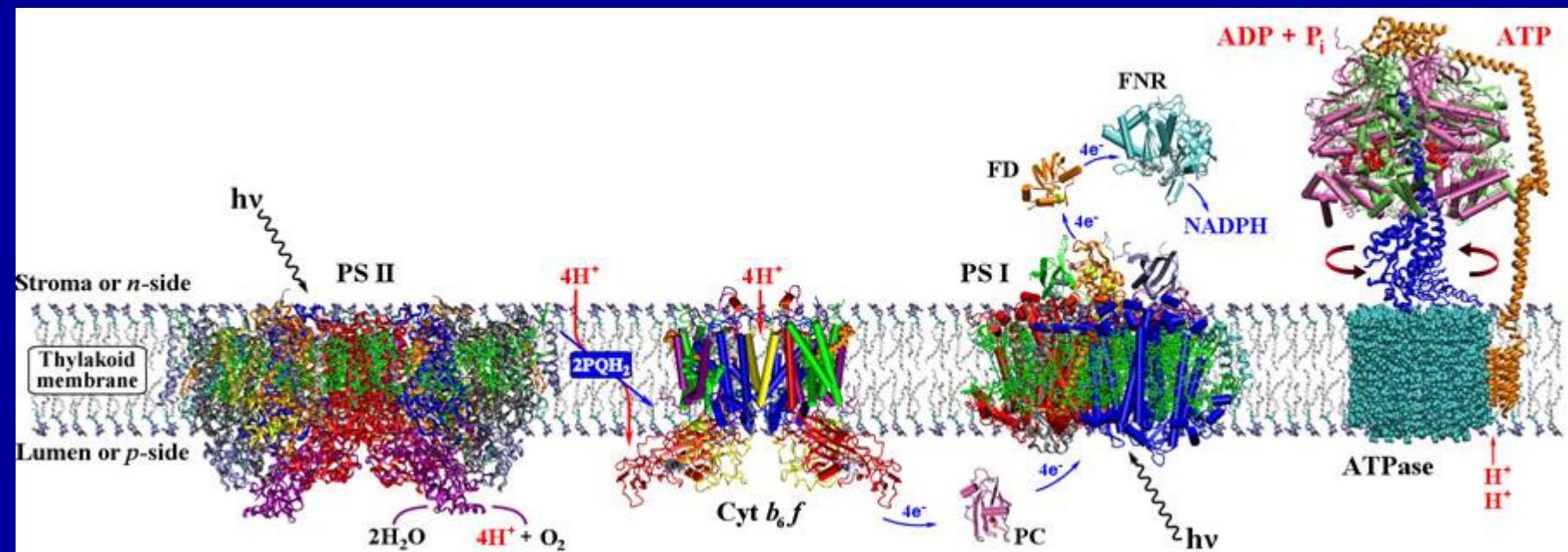
Examples of photosynthetic organisms:

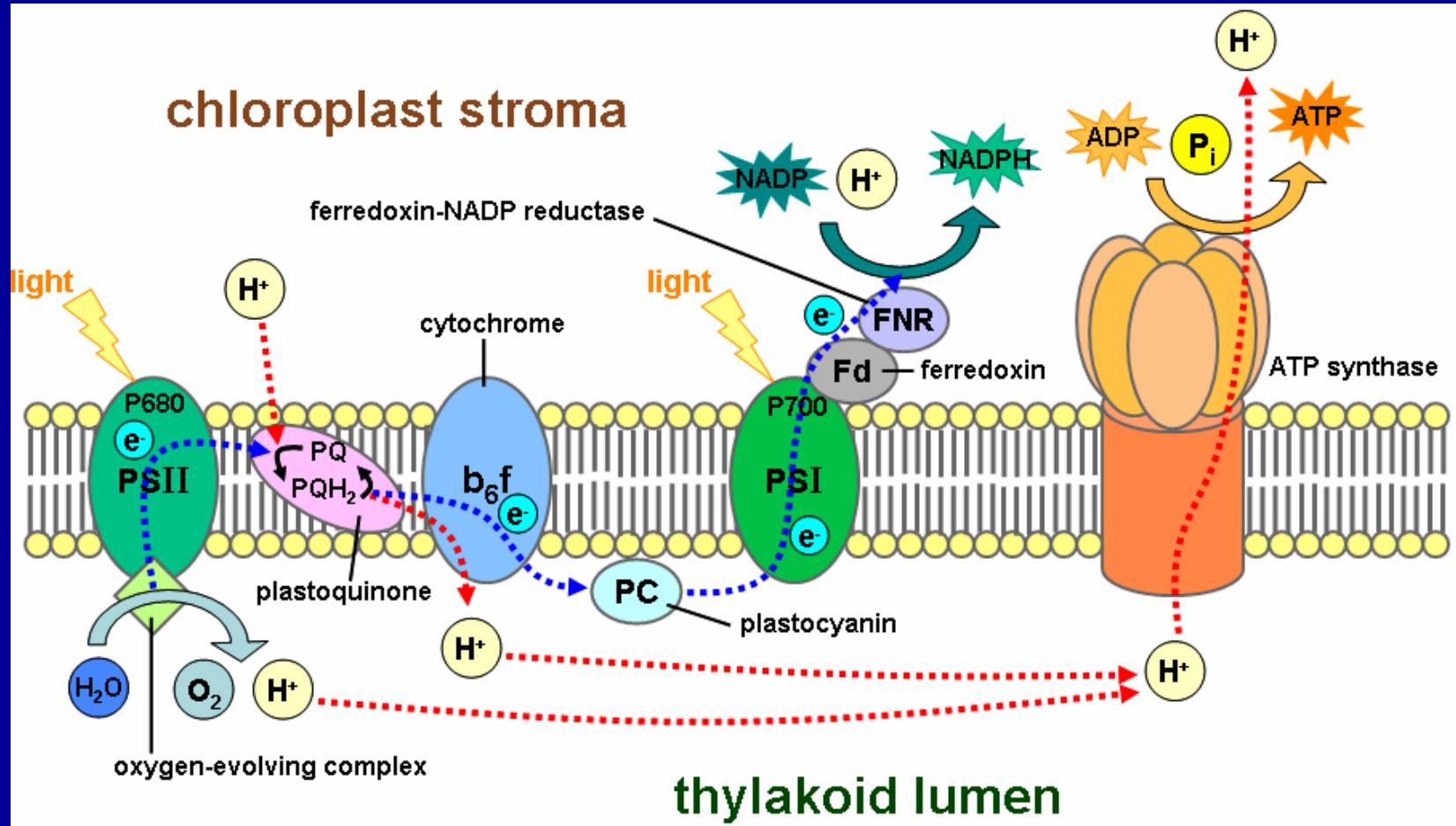
- leaves from higher plants
- photosynthetic purple bacteria
- cyanobacteria

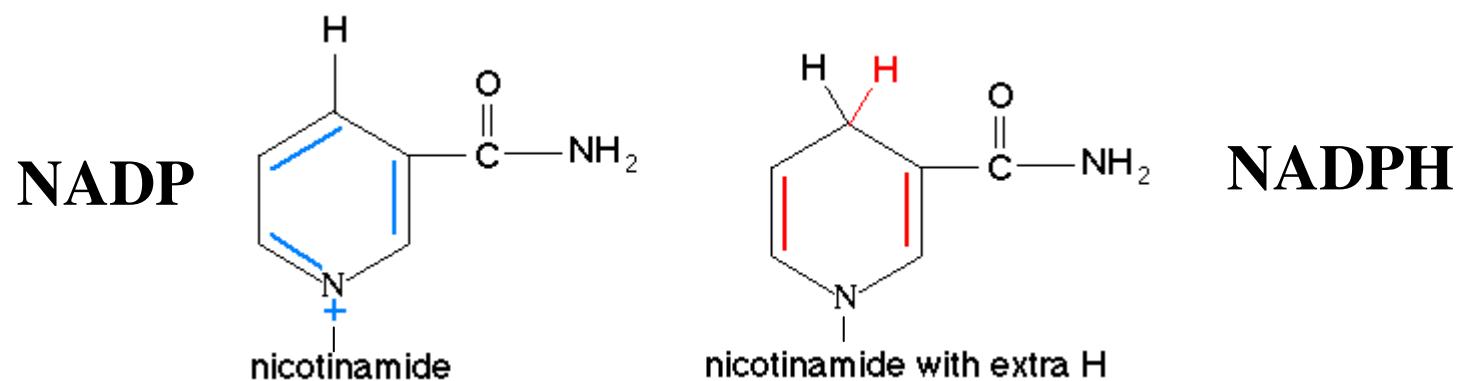
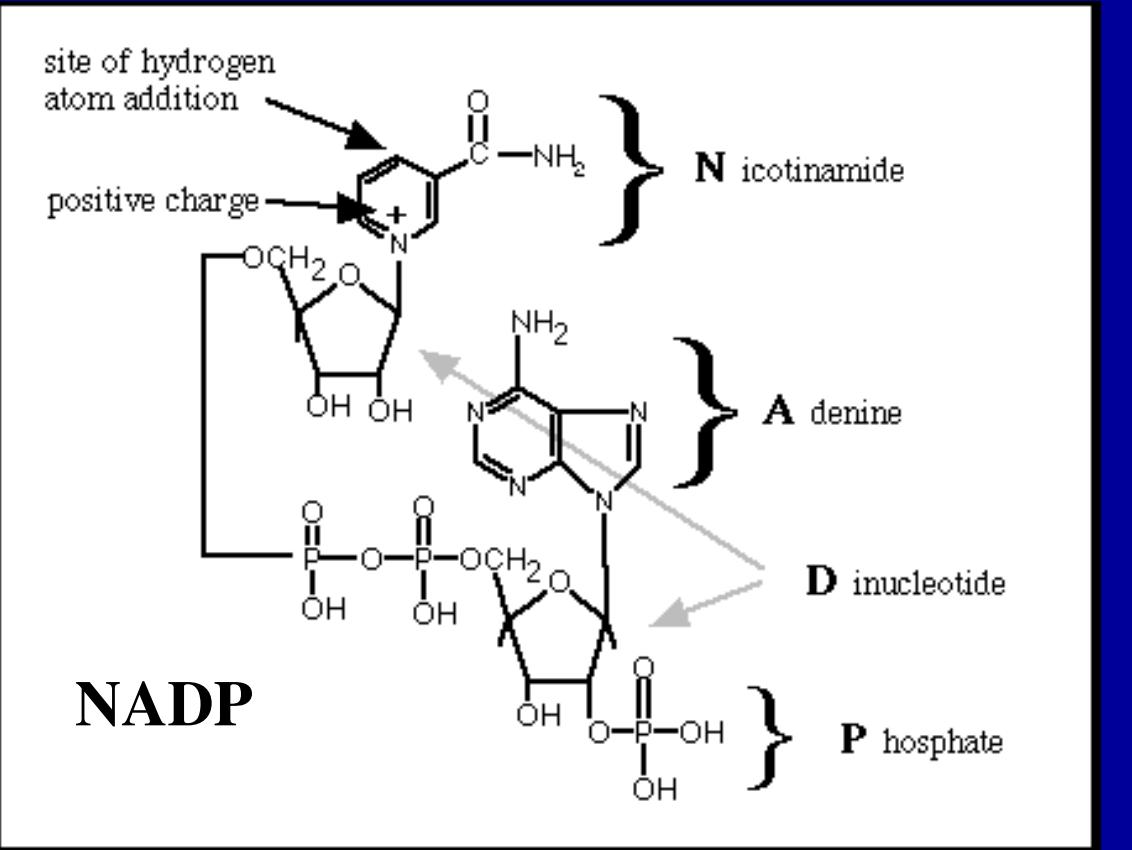
Green plant photosynthetic membrane



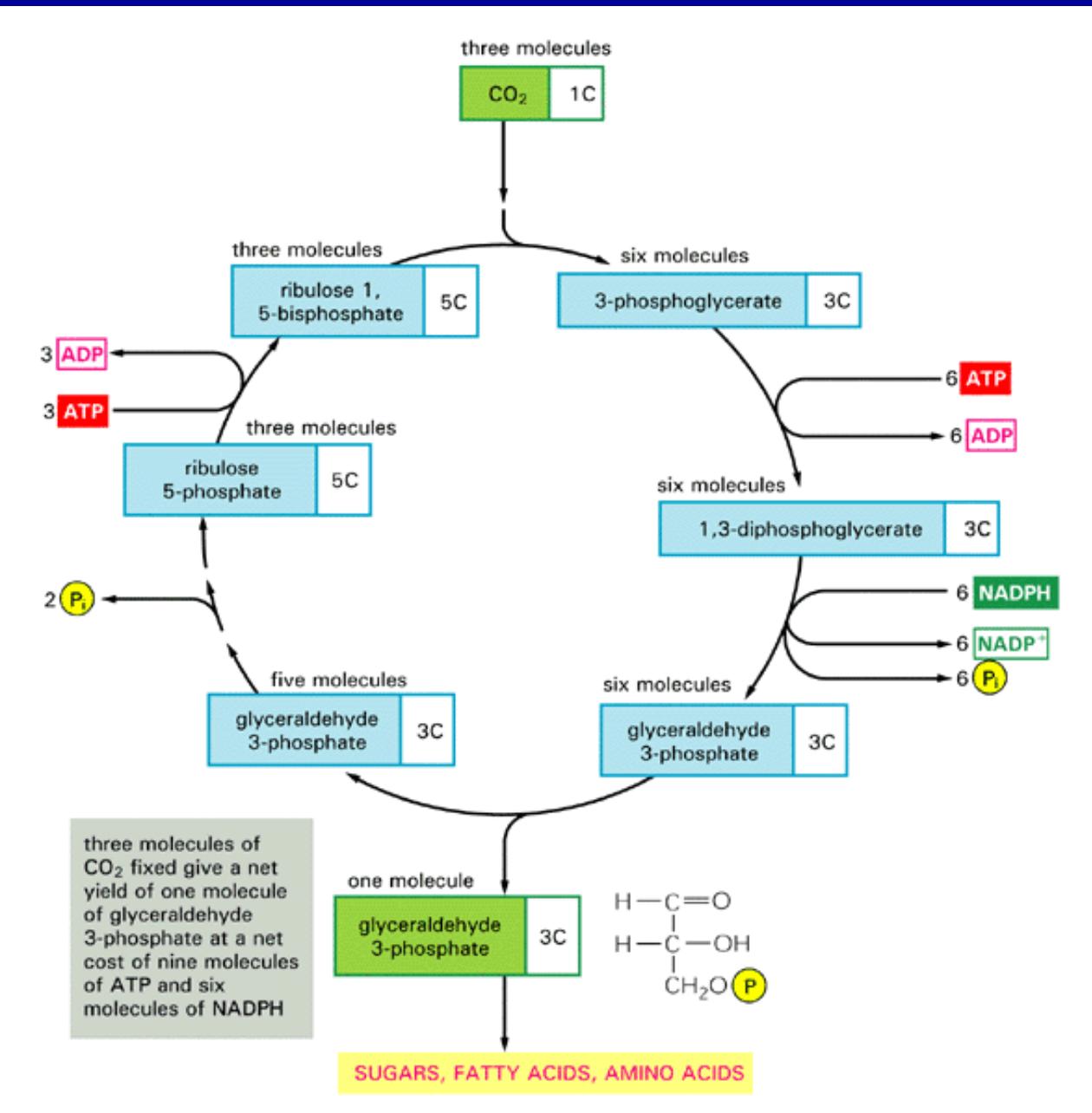
The photosynthetic membrane

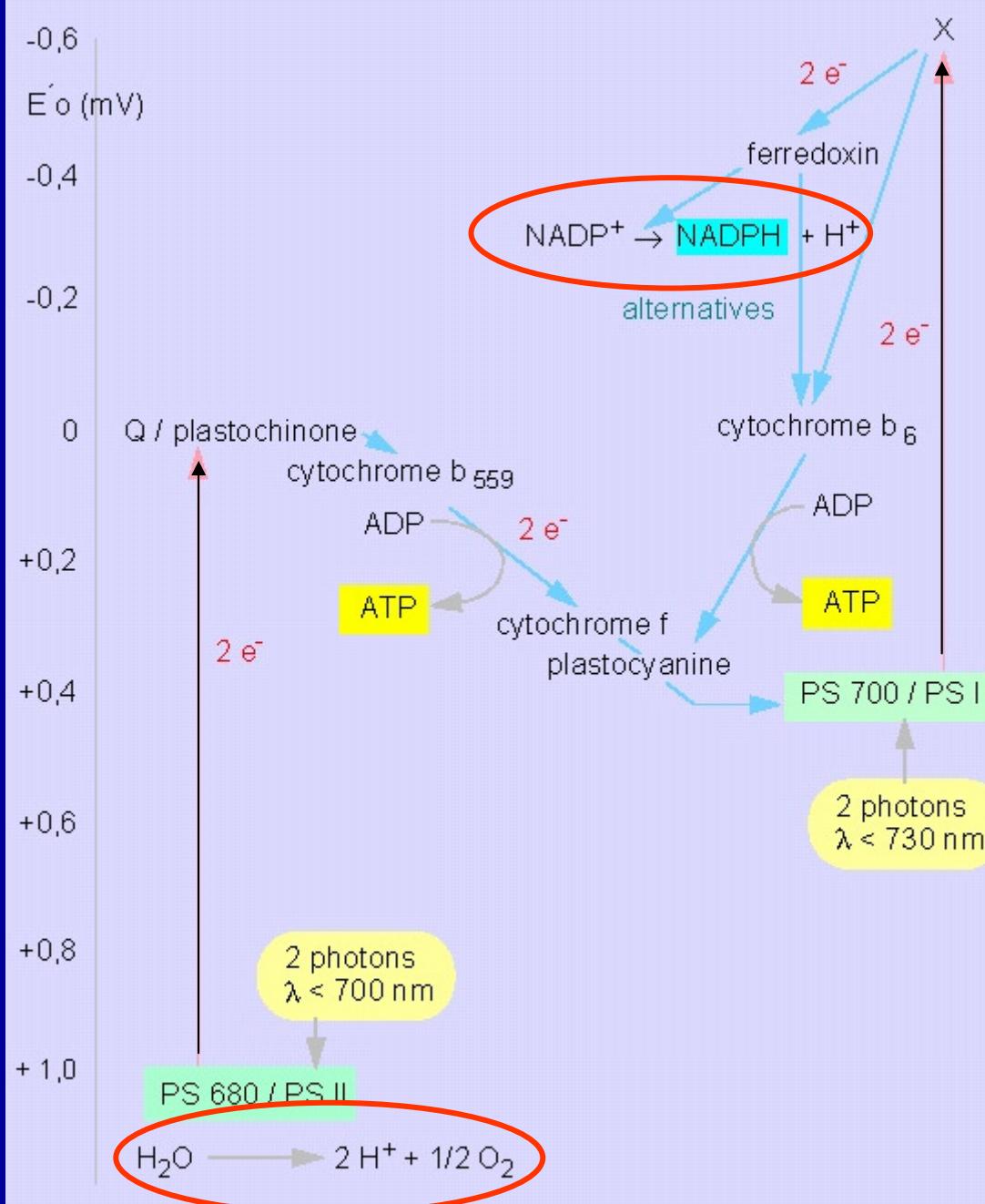




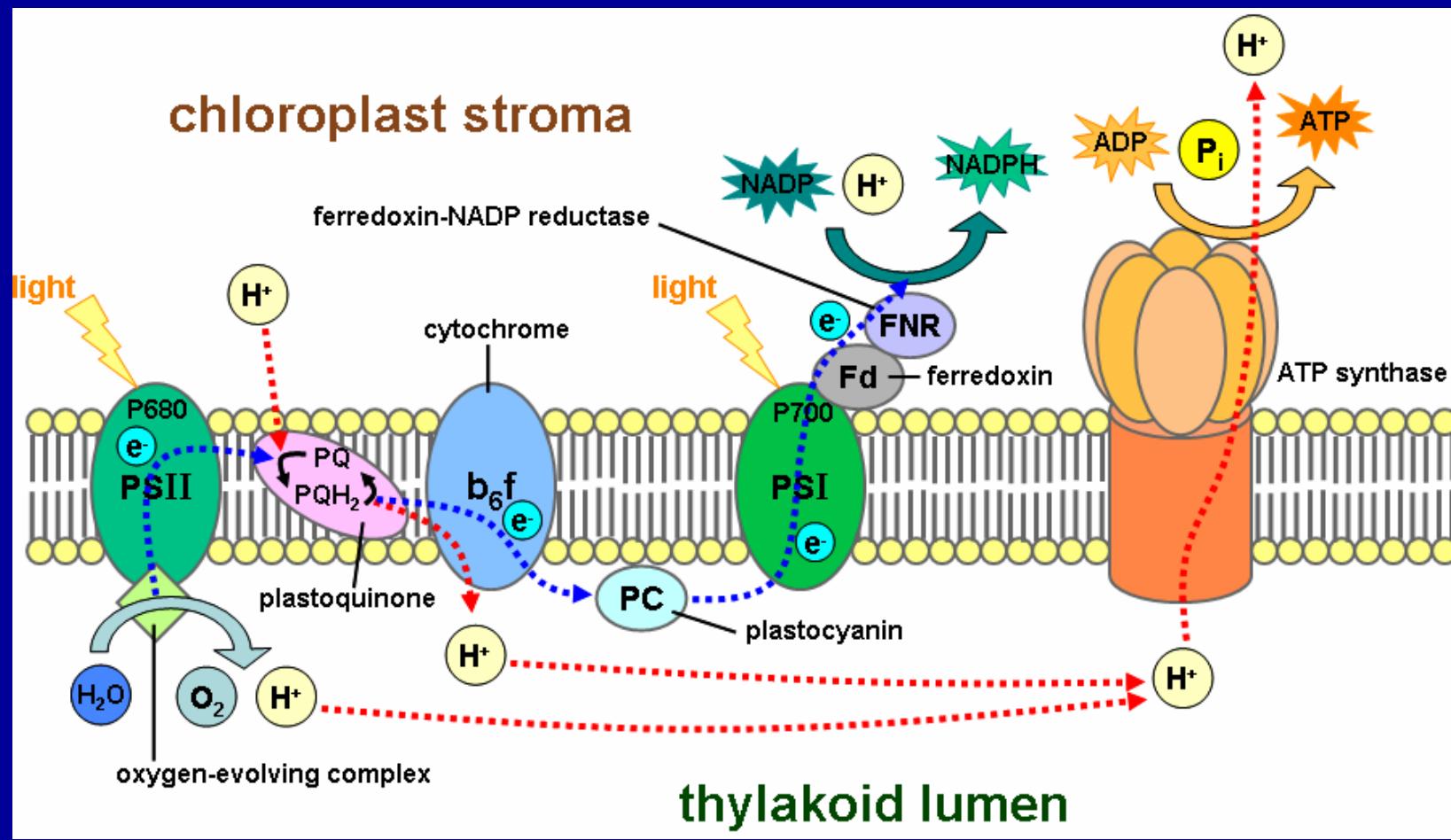


Calvin Cycle

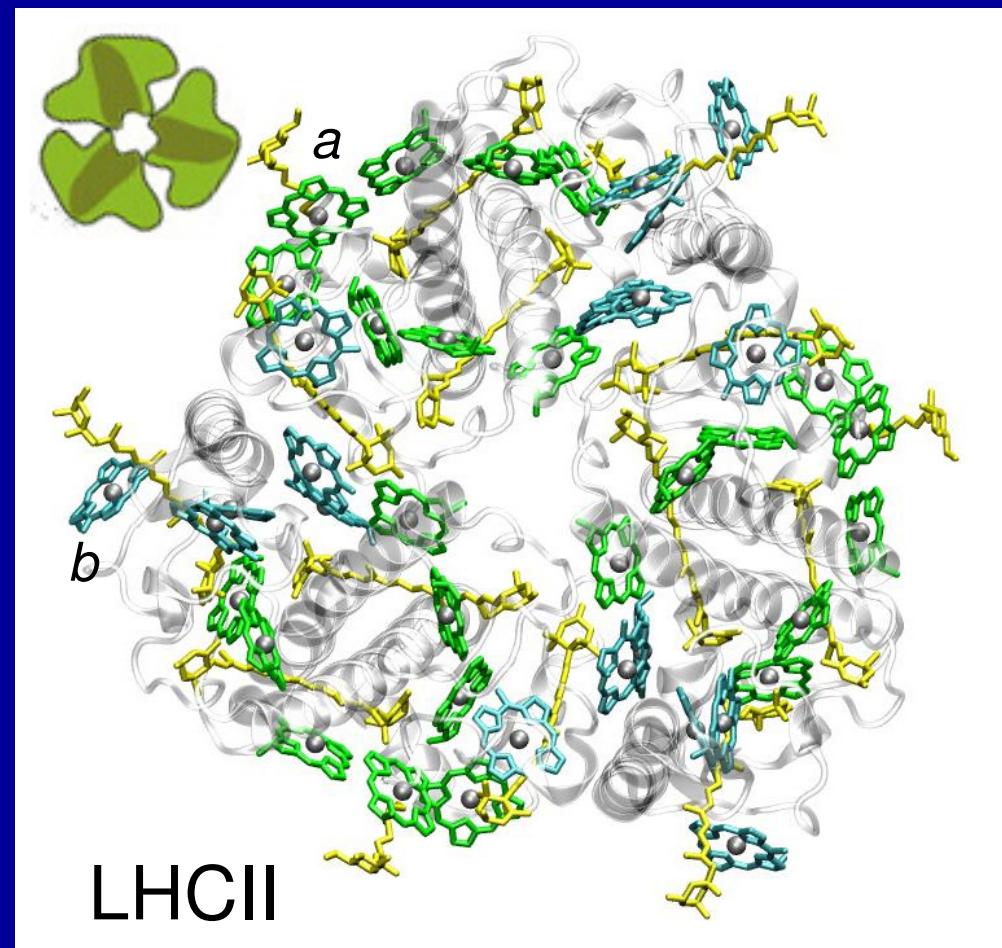
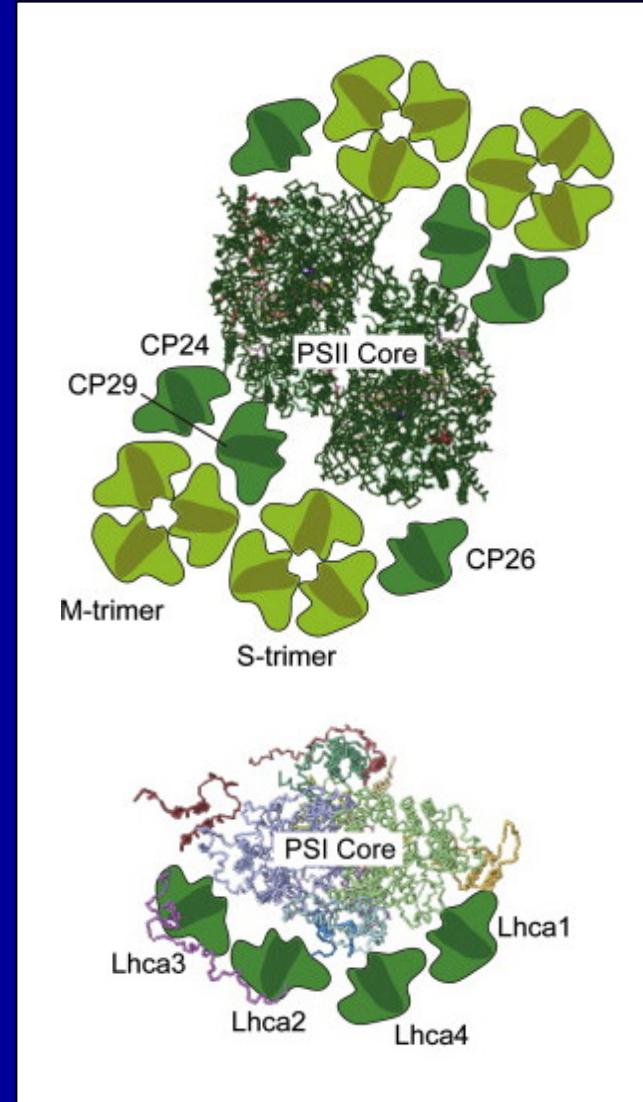




- ▶ In oxygen-evolving photosynthesis PSII and PSI function in parallel.
- ▶ Their excitation levels must be balanced to maintain an optimal photosynthesis.
- ▶ State transitions balance the absorbed light energy between the two photosystems.



The antenna systems of green plant photosynthetic membrane

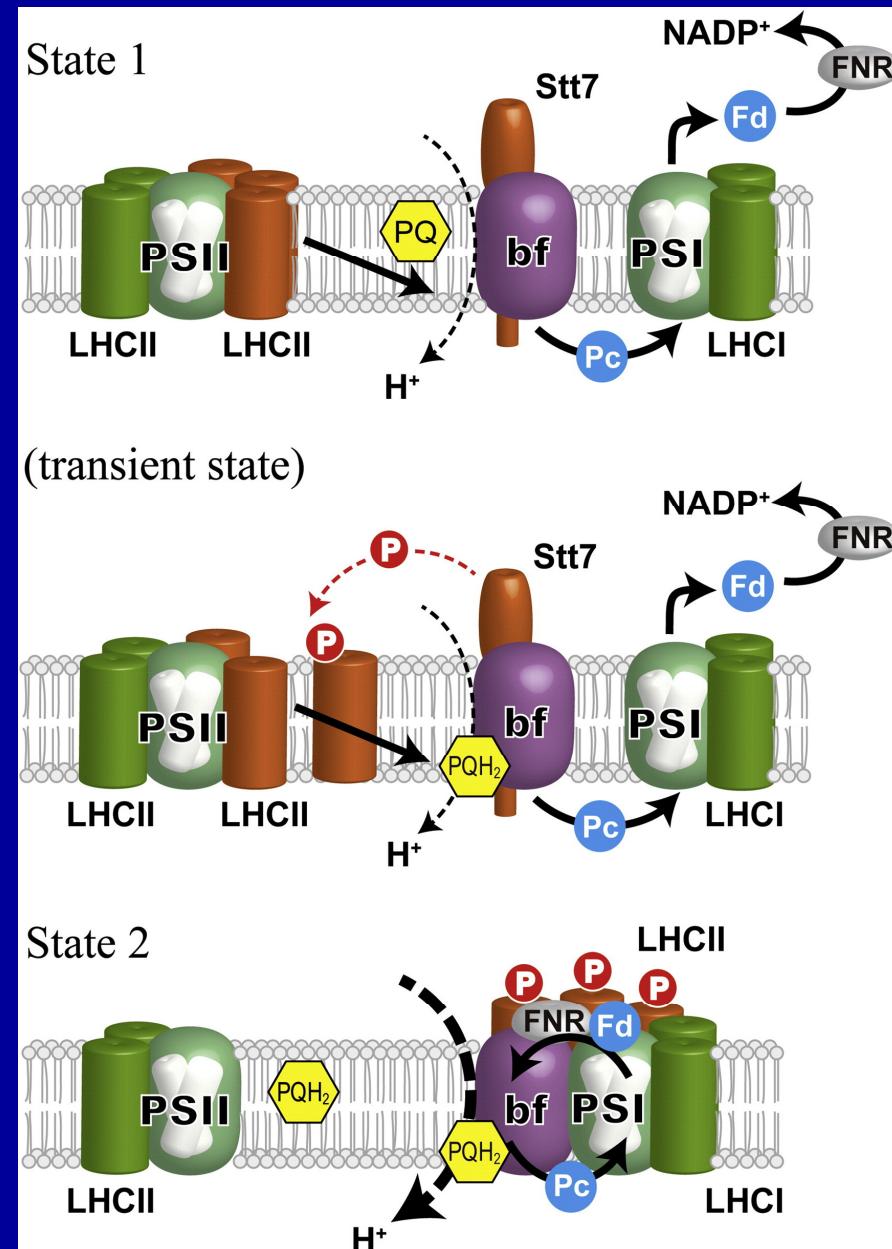


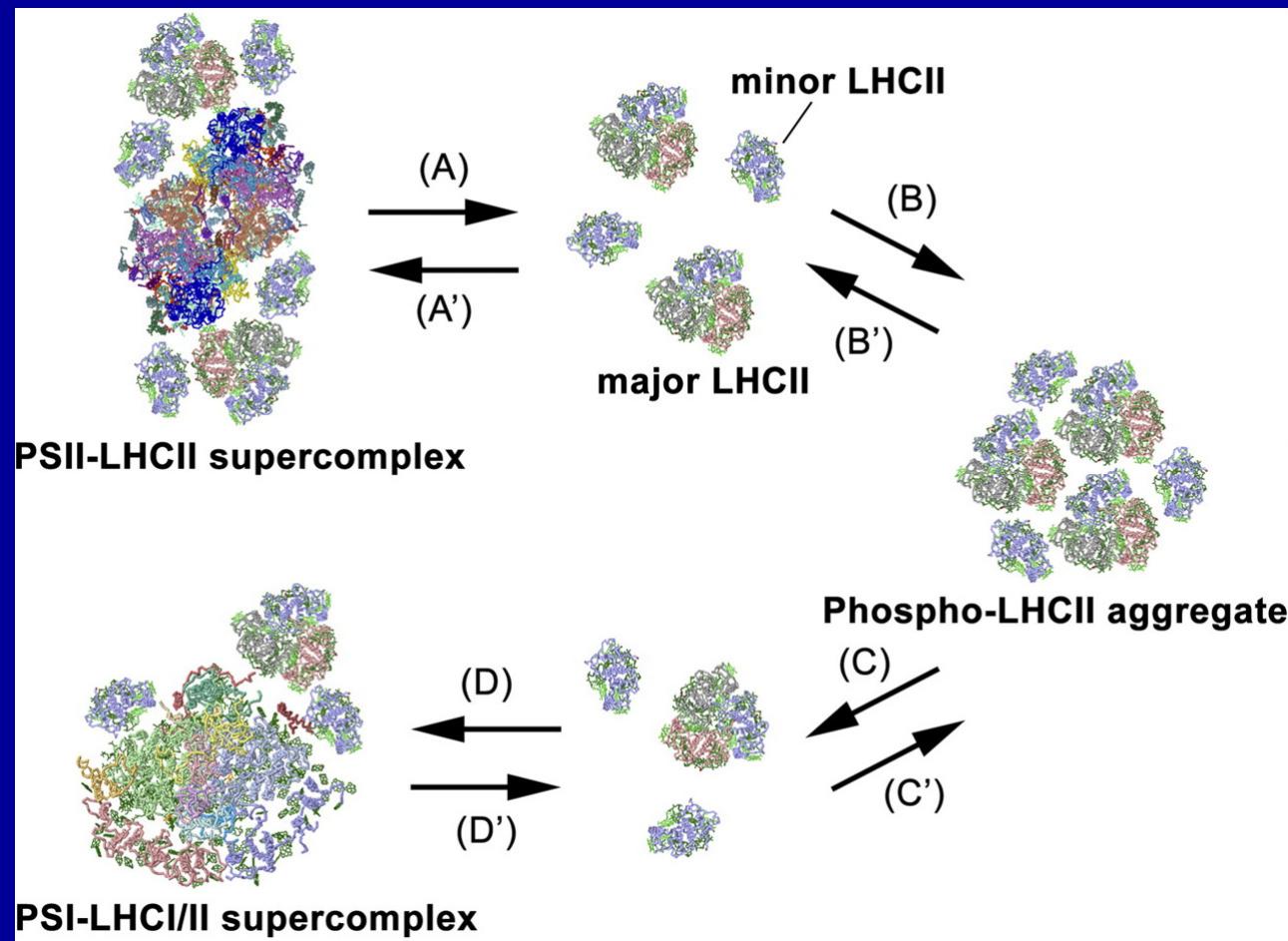
Schematic representation of the regulation of state transitions.

State 1, when PSI is preferentially excited, the PQ pool is oxidized. In this state, LHCIIIs are bound to PSII. The photosynthetic electron flow proceeds in LEF mode generating a proton gradient across the thylakoid membrane that is used for ATP production, as well as NADPH.

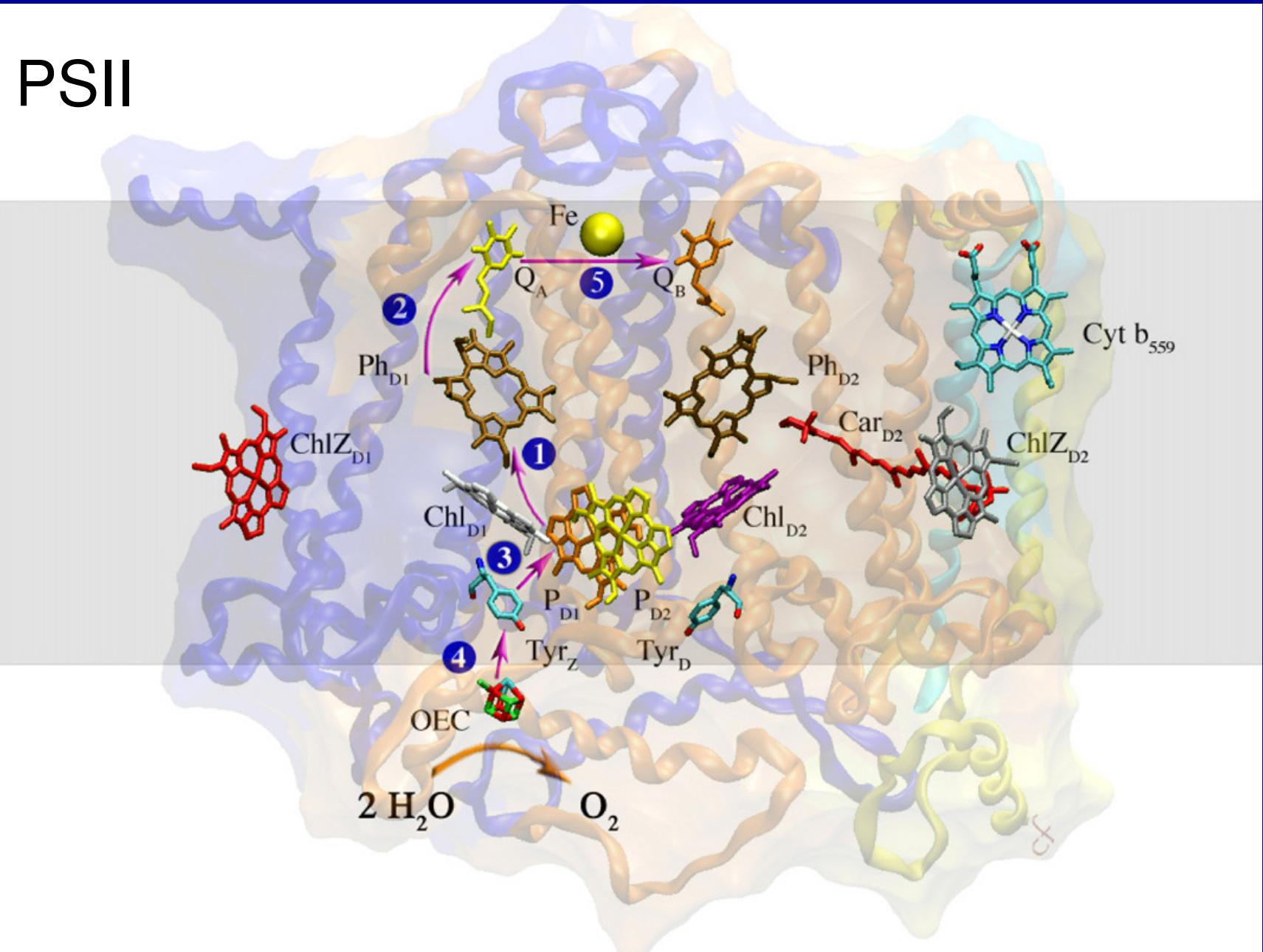
In the transient state at the onset of the preferential excitation of PSII, the PQ pool gets reduced. Docking of PQH₂ to the Qo-site of Cyt bf leads to the activation of the Stt7 kinase, which is required for the phosphorylation of LHCIIIs, causing the undocking of the mobile LHCIIIs (orange) from PSII.

State 2, the reassociation of mobile LHCII occurs on the PsaH side of PSI that is on the opposite side of the LHCI belt. Cyt bf and FNR are also bound to PSI to form a super-superc complex (CEF supercomplex), which is required to establish CEF between PSI and the PQ pool generating mostly ATP. bf, Cyt bf; PQ/PQH₂, plastoquinone/plastoquinol; Pc, plastocyanin; Fd, ferredoxin.



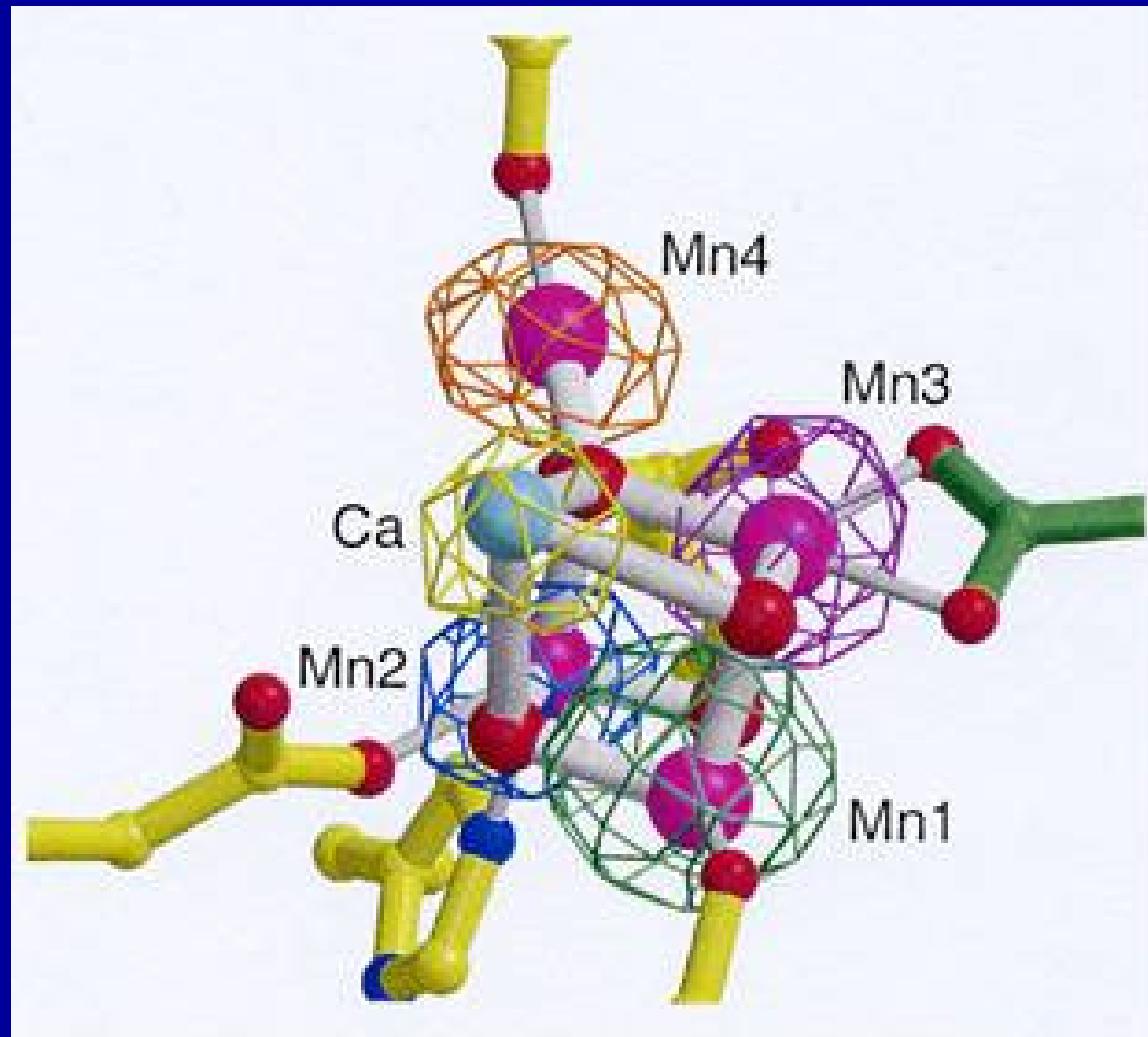


PSII



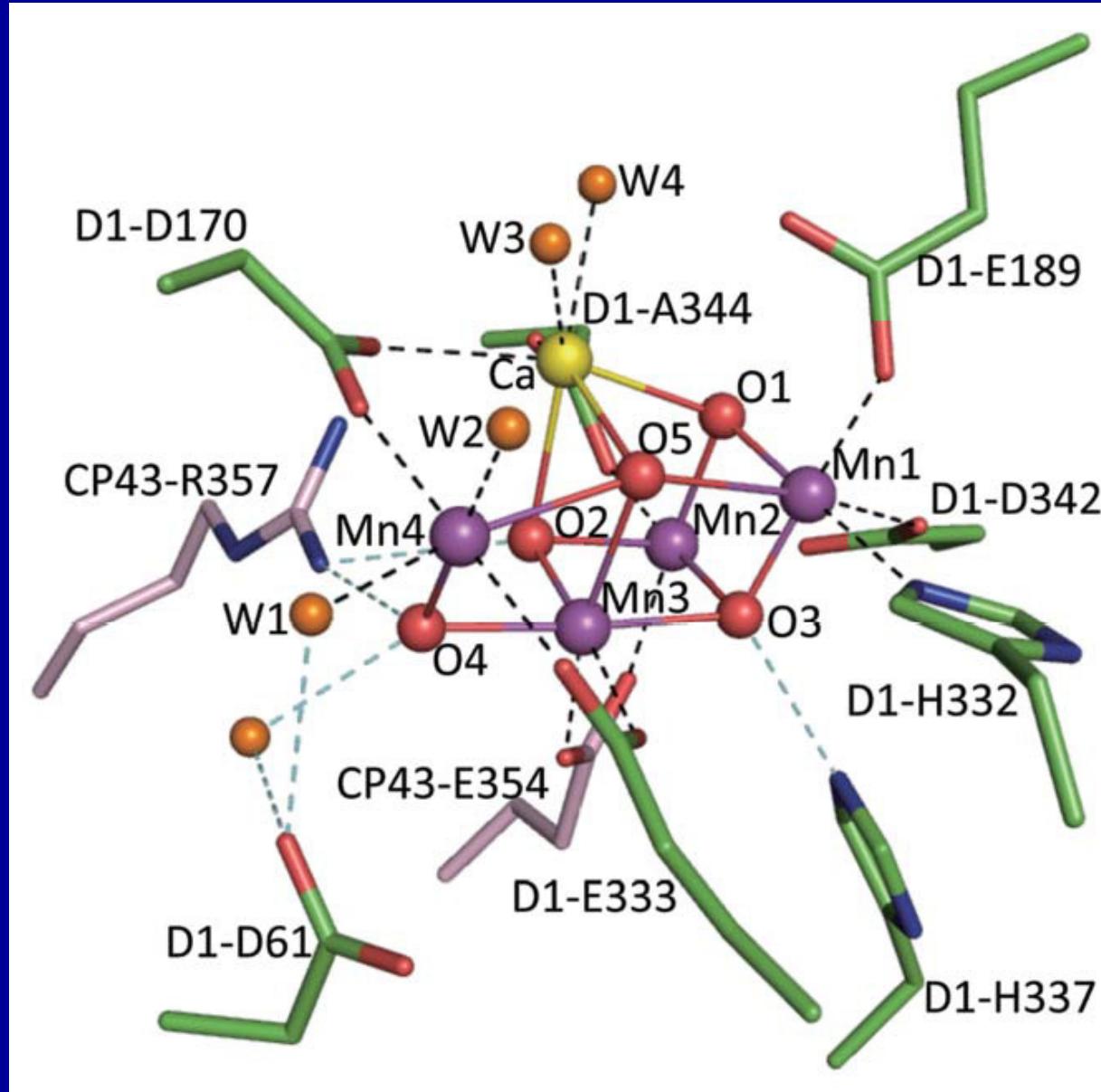
Oxygen Evolving Complex in PSII (Mn_4Ca)

OEC structure, res. 3.5 Å



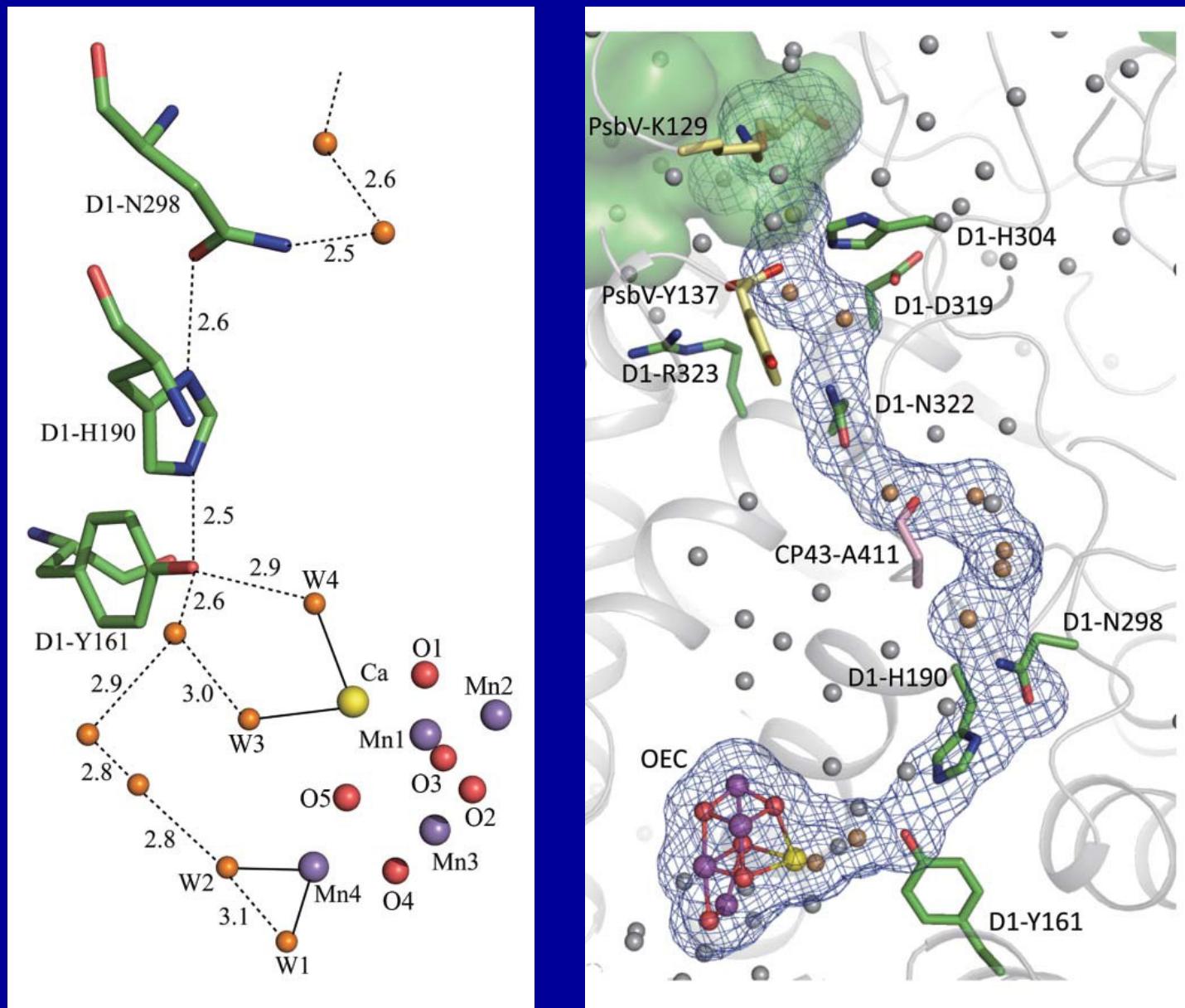
K. N. Ferreira, T. M. Iverson, K. Maghlaoui, J. Barber, S. Iwata *Science* **2004**, *303*, 1831-1838

OEC structure, res. 1.9 Å



Y. Umena, K. Kawakami, J-R. Shen, and N. Kamiya, *Nature* 2011, **473**, 55-60.

OEC, hydrogen bonding network



Y. Umena, K. Kawakami, J-R. Shen, and N. Kamiya, *Nature* 2011, **473**, 55-60.

