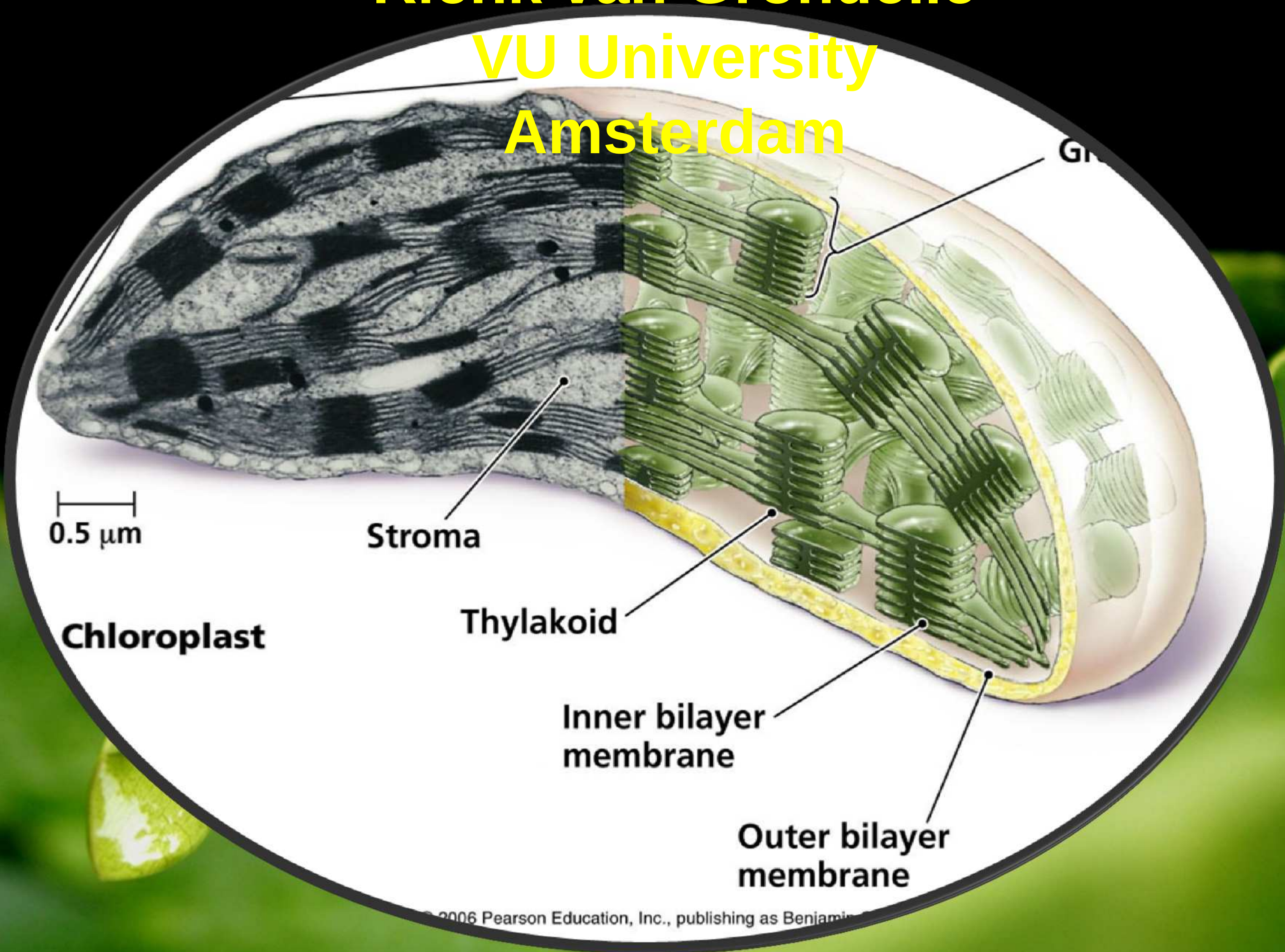
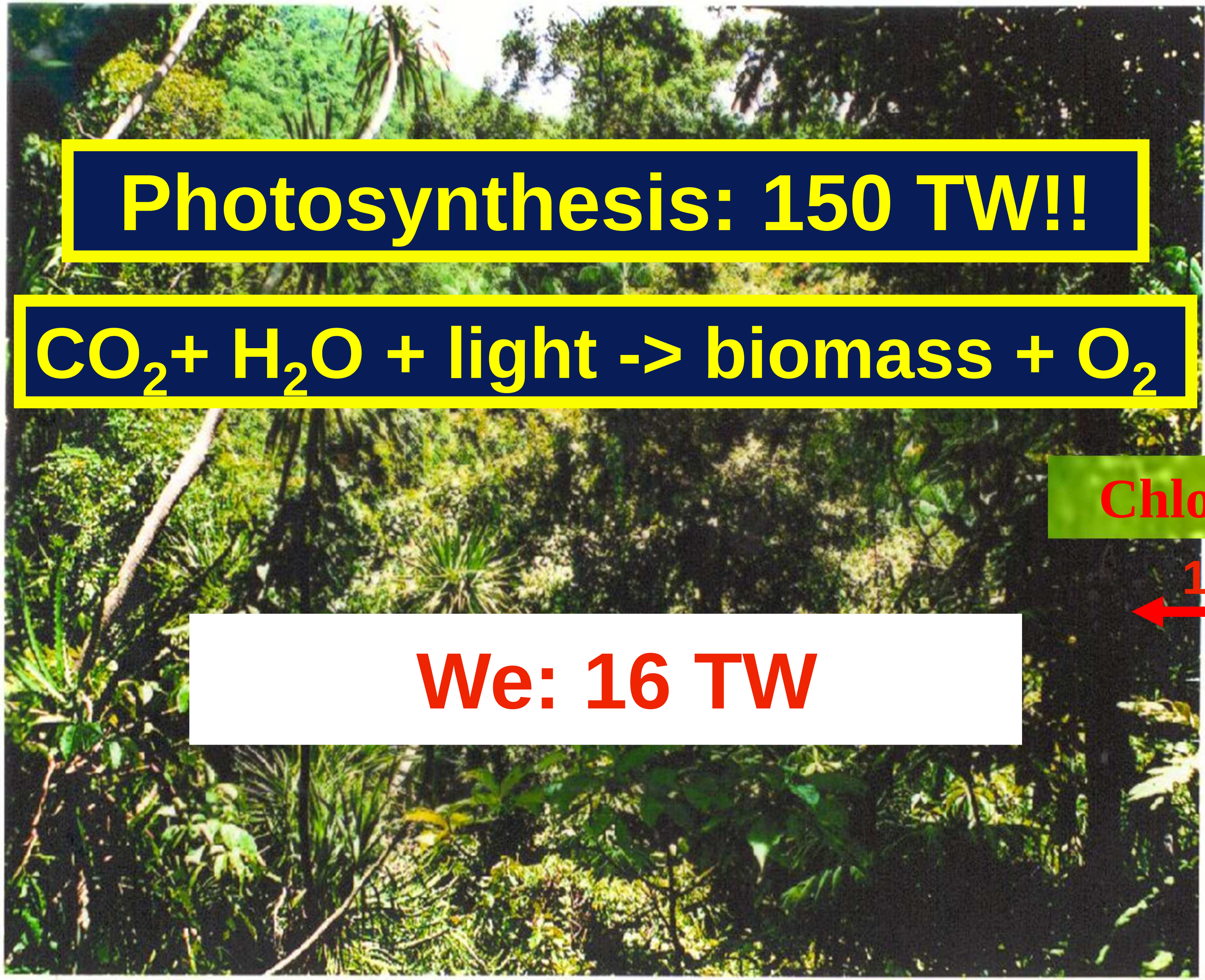
"Photosynthesis and Fuel/Food Supply"

Rienk van Grondelle
VU University
Amsterdam

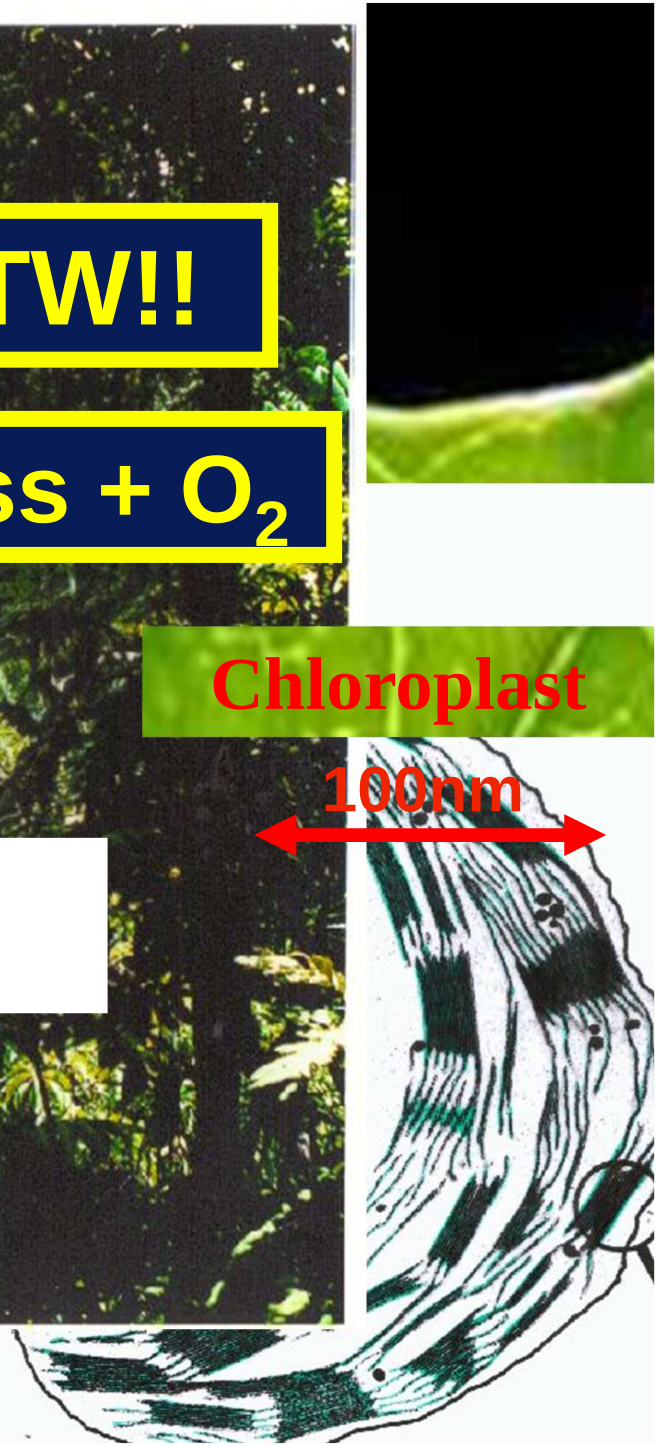


Photosynthesis: 150 TW!!

$CO_2 + H_2O + \text{light} \rightarrow \text{biomass} + O_2$



We: 16 TW



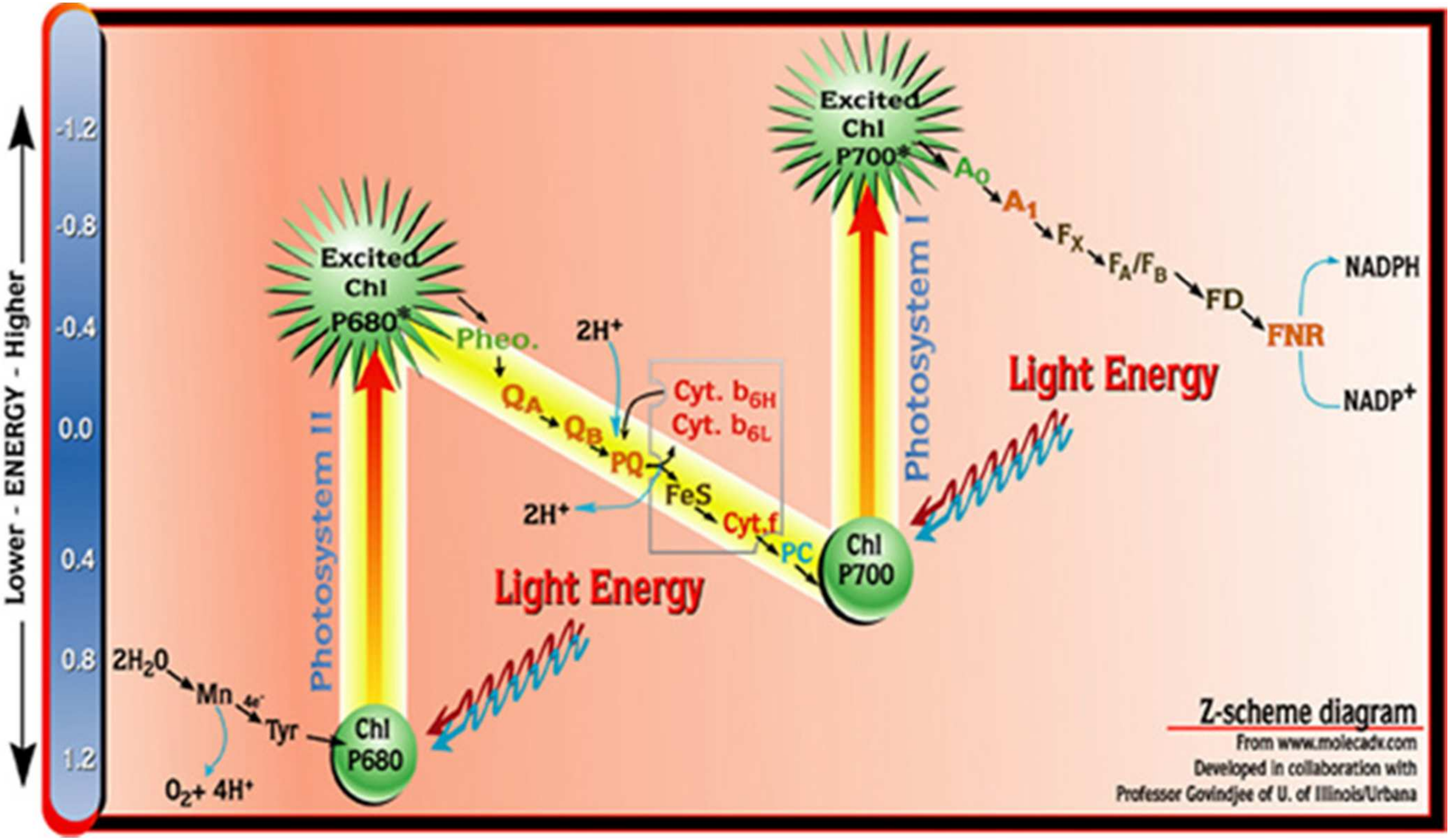
105 billion tons per year

of biomass is produced by photosynthesis

= two great pyramids of Giza per hour... every hour

of biomass

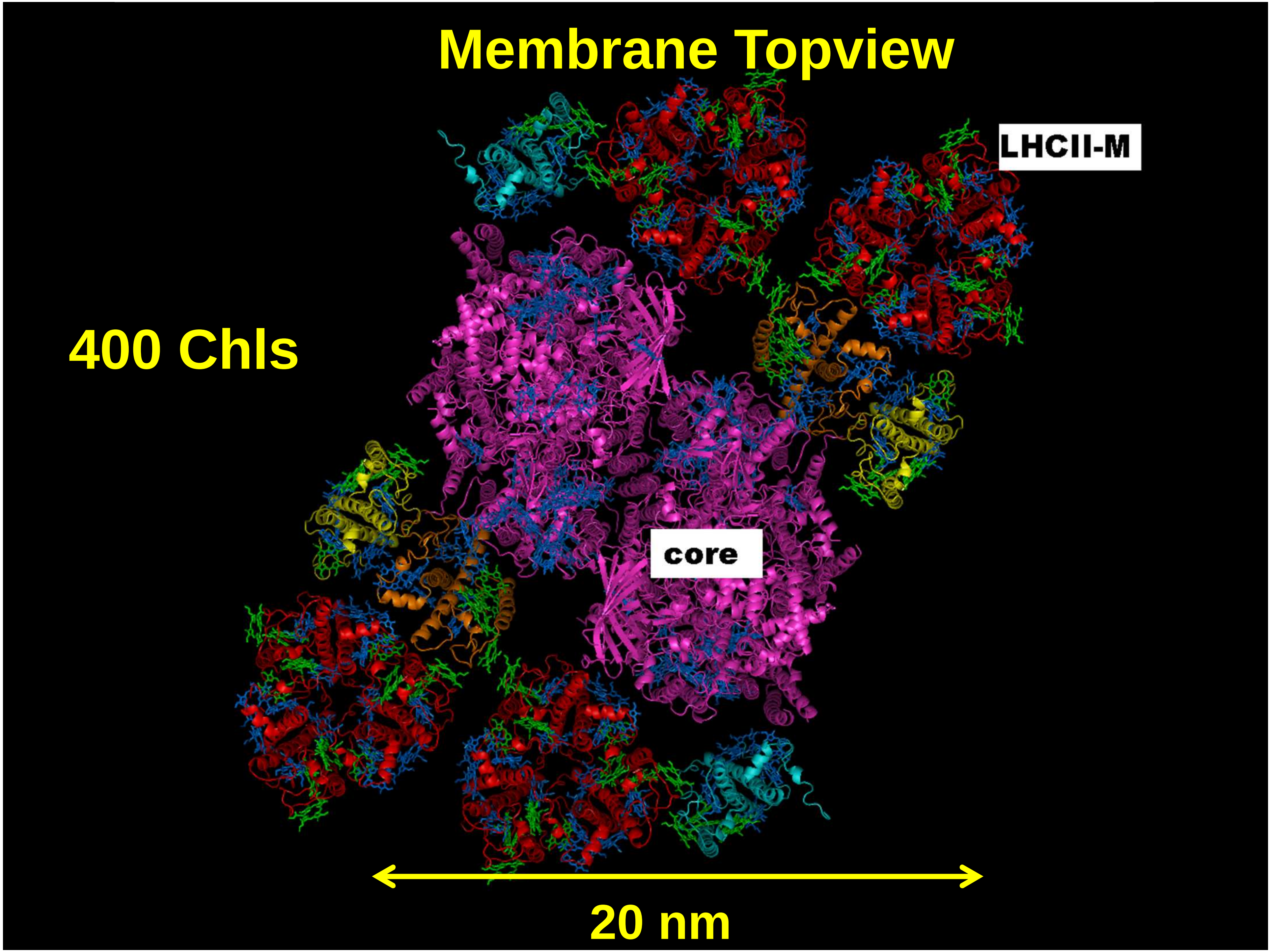
Photosynthesis involves two light reactions in series: Photosystem 1 to reduce CO_2 and Photosystem 2 to oxidize H_2O



Lessons From Nature For Solar Fuels

1. A plant in your windowsill absorbs all the incident light:

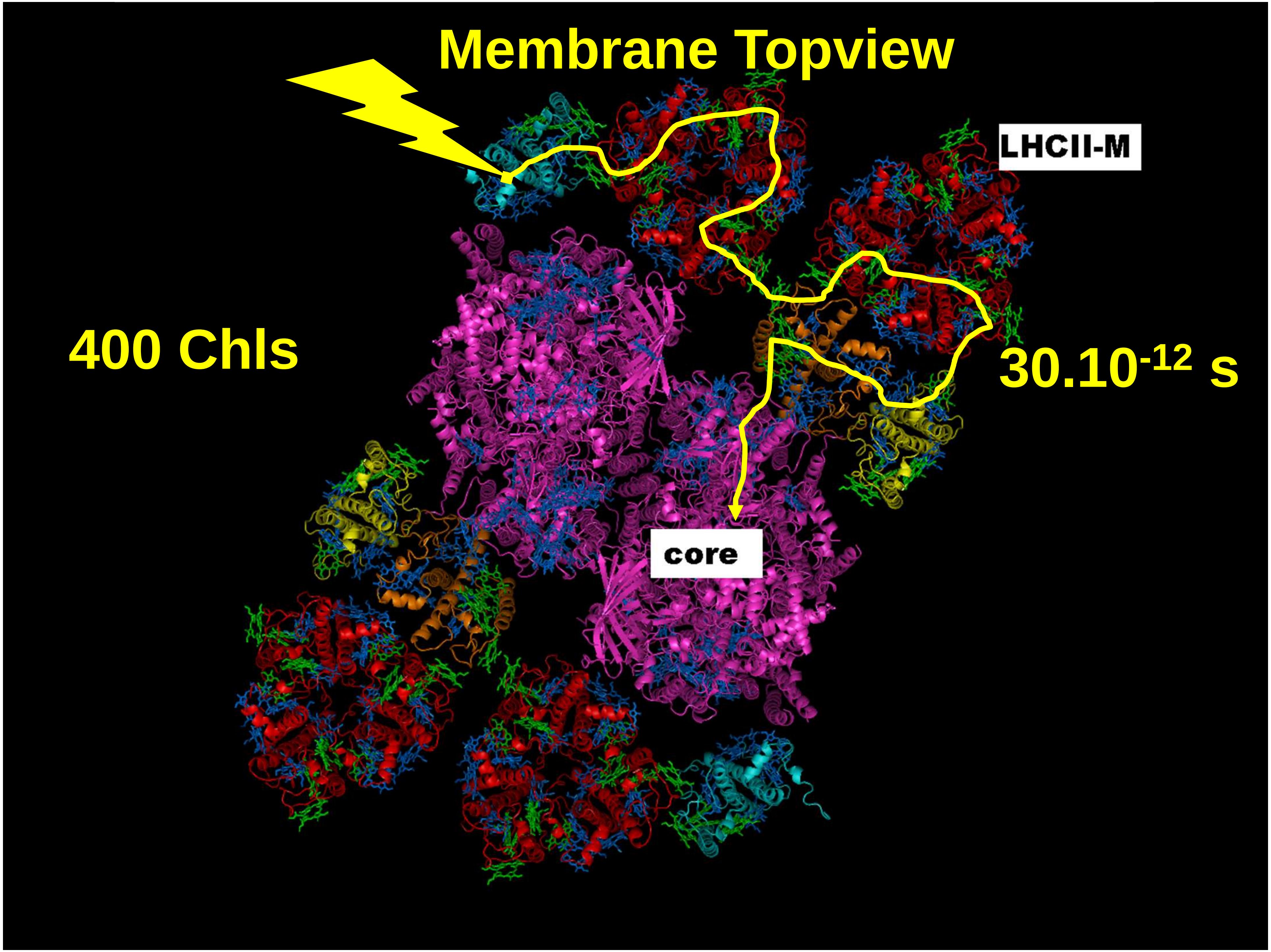
on an average sunny day 10^6 photons per second thanks to highly concentrated chlorophylls in proteins organized in the thylakoid membrane


Membrane Topview
400 Chls
LHCII-M
core
20 nm

Lessons From Nature For Solar Fuels

1. *A plant in your windowsill absorbs all the incident light: 10^6 photons per second thanks to highly concentrated chlorophylls in proteins*

2. **A photosynthetic excitation can be transferred over 1000s of chlorophylls without getting lost thanks to superposition states and coherence**

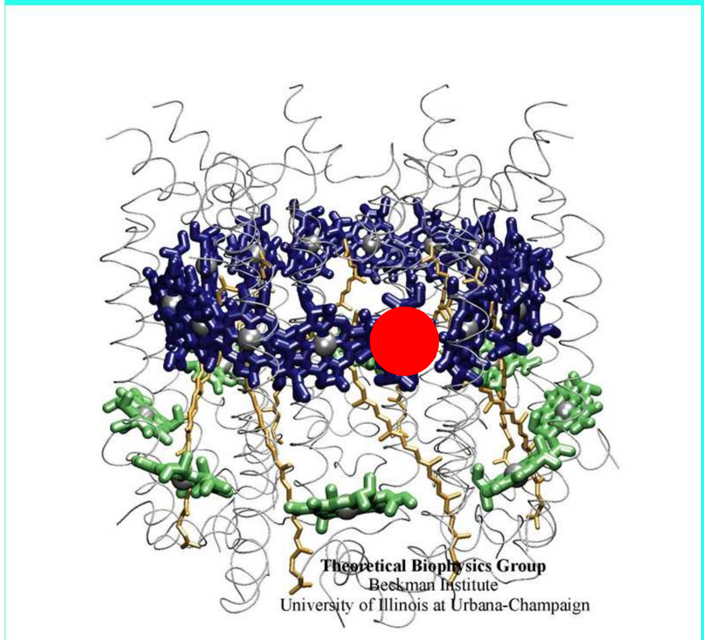

Membrane Topview
LHCII-M
400 Chls
30.10-12 s
core

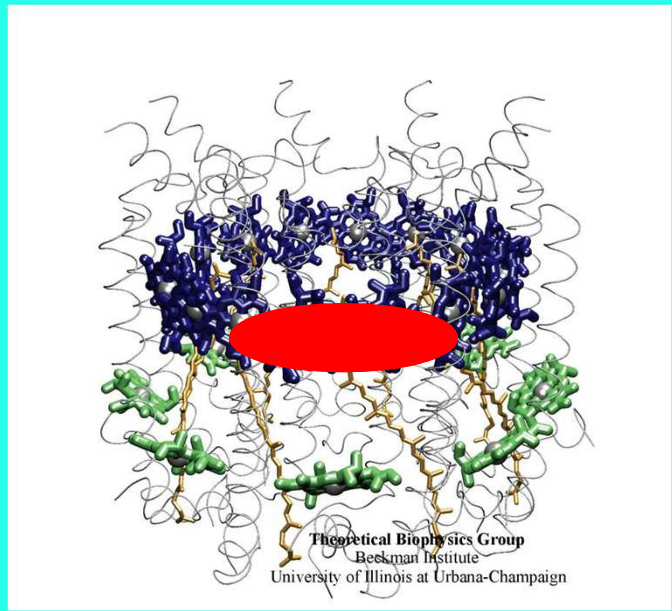
Delocalized Excitations

$$\varphi_i \quad \textbf{vs} \quad \psi_k = \sum_{i=1}^{N} c_{ki}\varphi_i$$

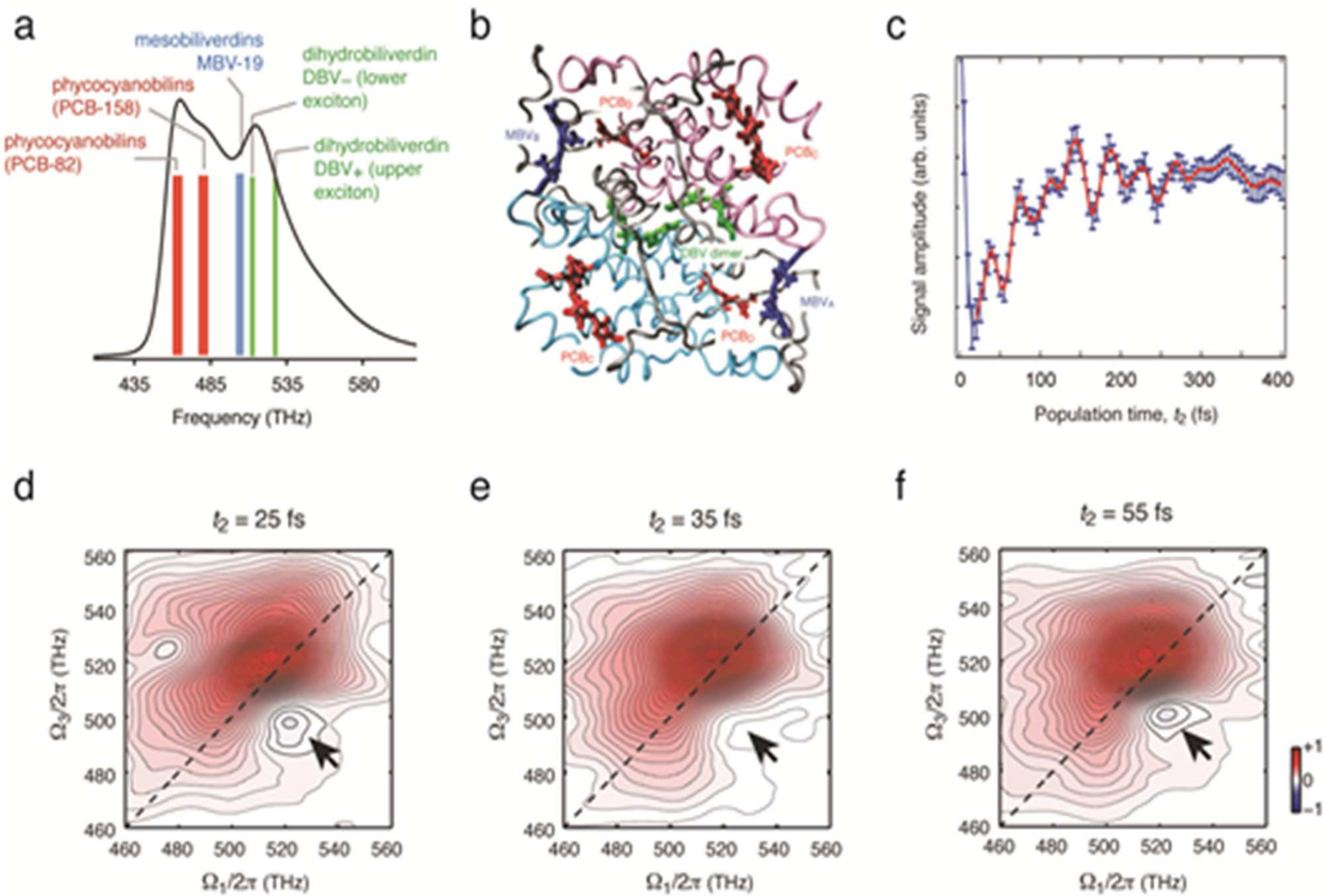
localized

delocalized





2D-ES to reveal Coherence



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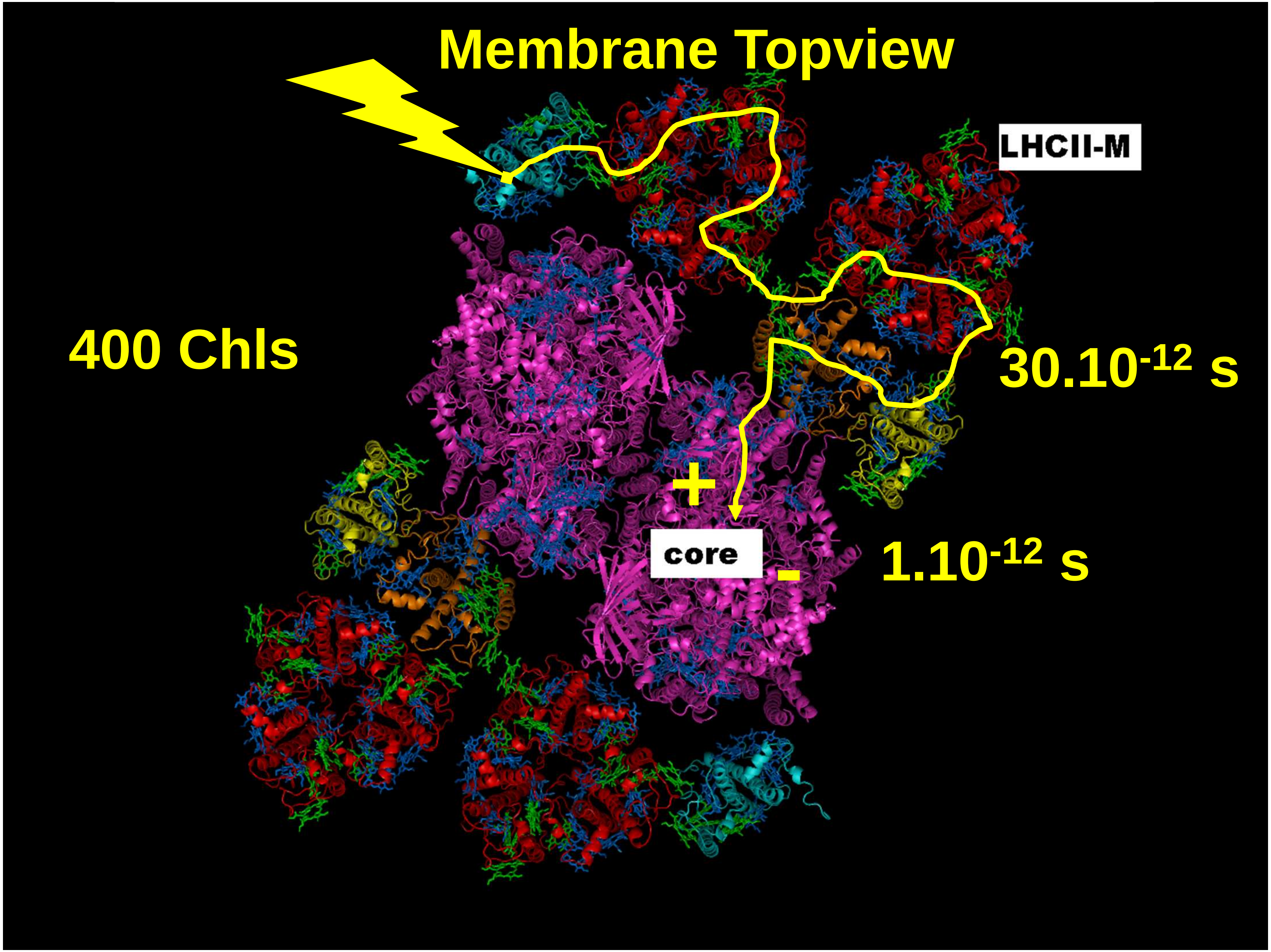
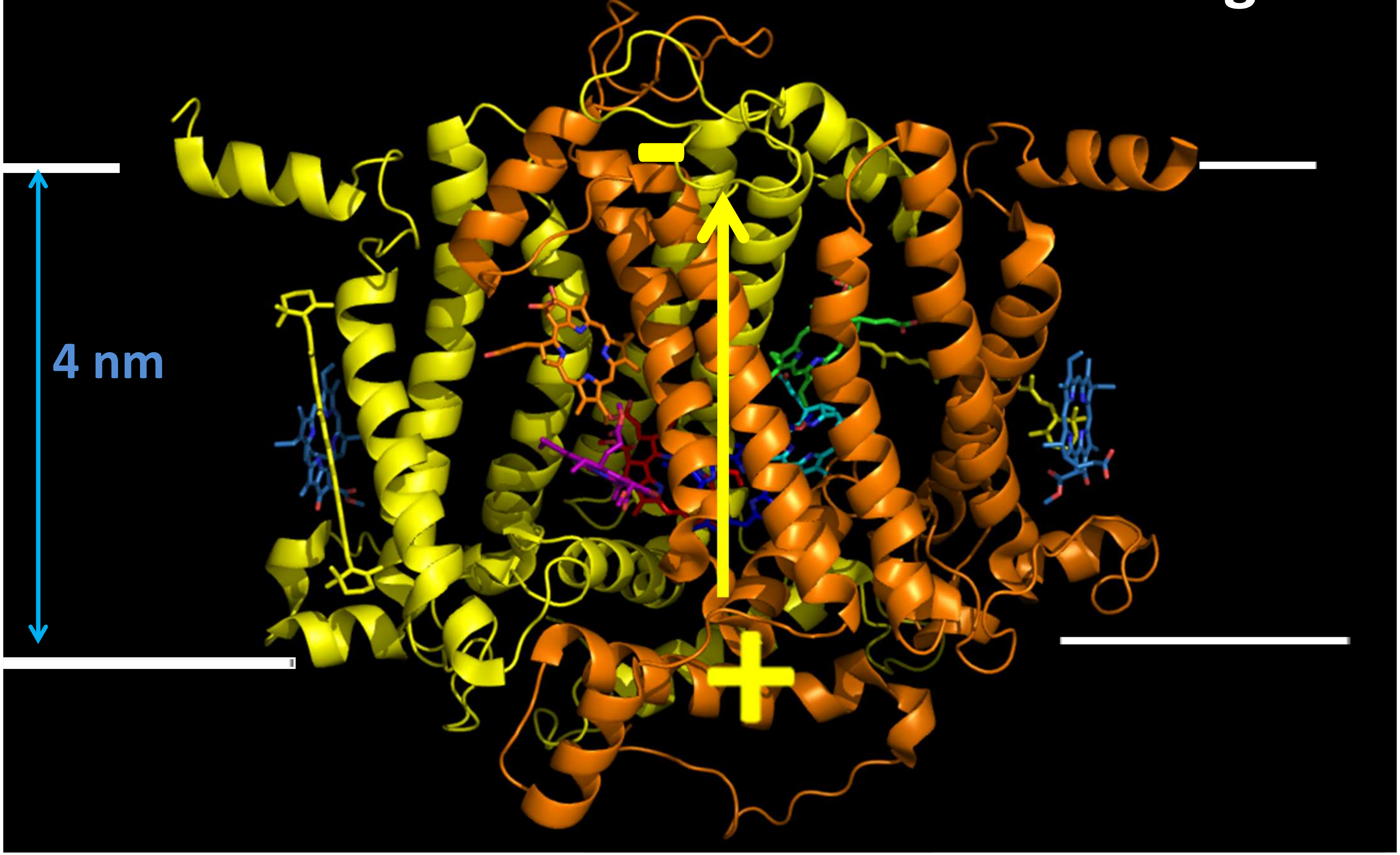
3. **Reaction centers separate charges by electron tunneling on a picosecond timescale**


Membrane Topview
LHCII-M
400 Chls
30.10^{-12} s
+
core
-
1.10^{-12} s

BioSolar Cell: The Reaction Center

Electron transfer = Electron Tunneling



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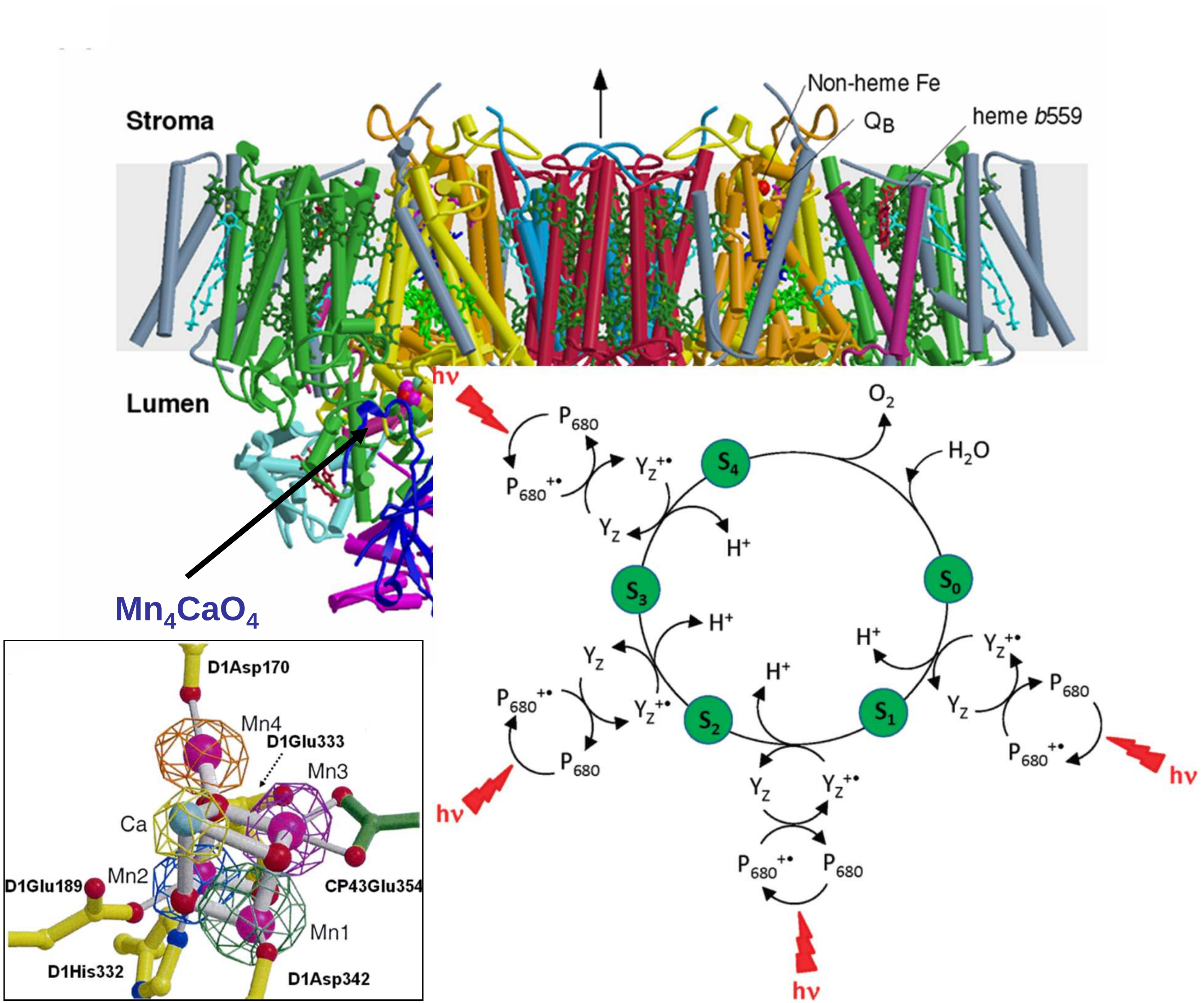
4. **Plants extract electrons from H_2O with a 'hole efficiency' of 1 using an ingenious complex management of electrons and protons**



Stroma
Non-heme Fe
Q_B
heme b559
Lumen
Mn_4CaO_4
D1Asp170
Mn4
D1Glu333
Mn3
Ca
Mn2
D1Glu189
CP43Glu354
Mn1
D1His332
D1Asp342
hν
P_{680}
$P_{680}^{+\bullet}$
$Y_Z^{+\bullet}$
Y_Z
H^+
S_4
O_2
H_2O
S_3
S_0
S_2
S_1

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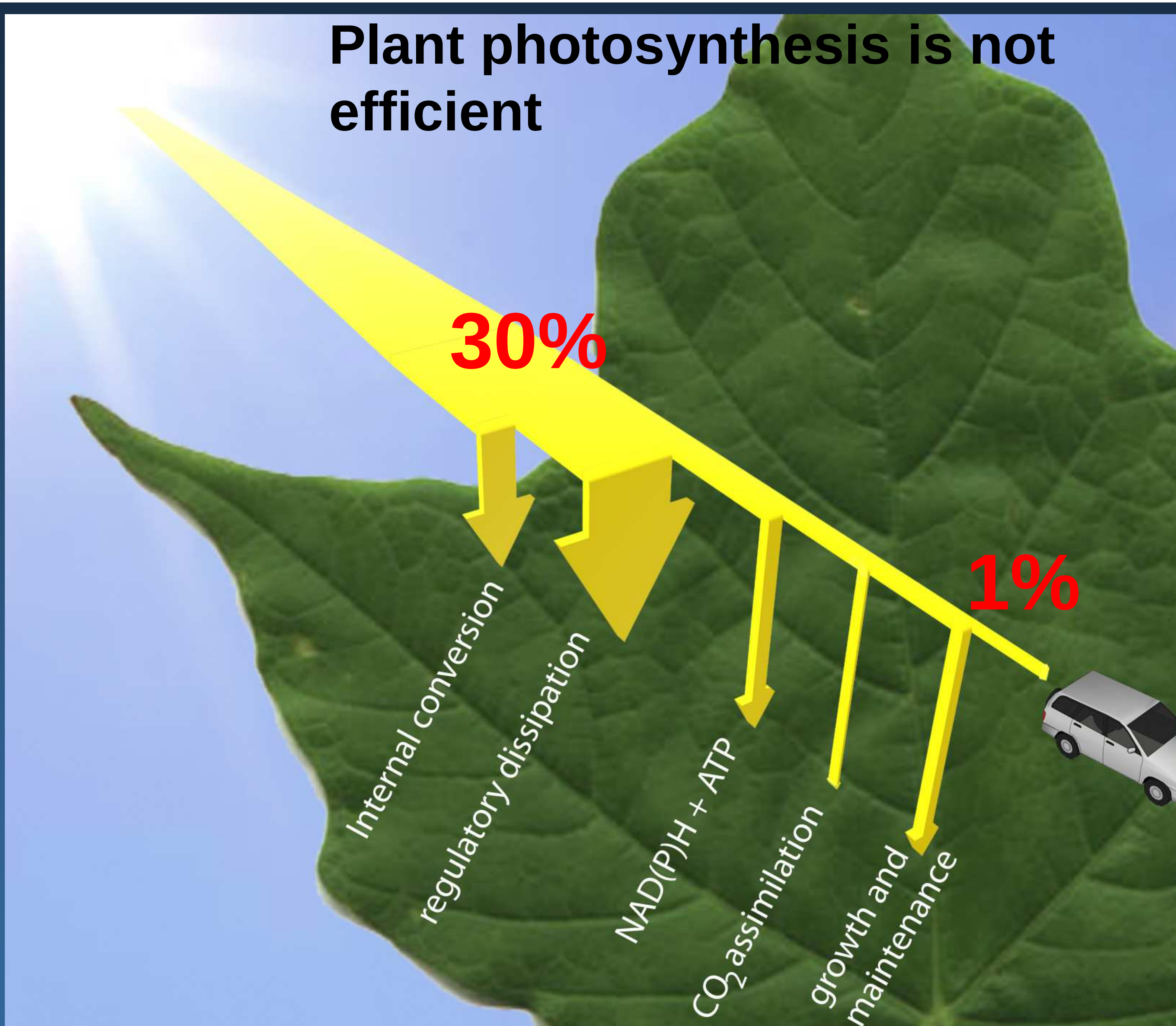
5. **Maximum energy efficiency solar->fuel is 30%, over the complete solar spectrum 12%, to biomass 2-3 % or less**

Plant photosynthesis is not efficient



Gust, Kramer, Moore, Moore & Vermaas, MRS Bulletin, 2008, in press

Solution: Artificial Photosynthesis

1. The artificial leaf
2. The bio-hybrid device
3. The photosynthetic ‘solar fuel cow’
4. Improving natural photosynthesis

Solution: Artificial Photosynthesis

1. **The artificial leaf**
2. *The bio-hybrid device*
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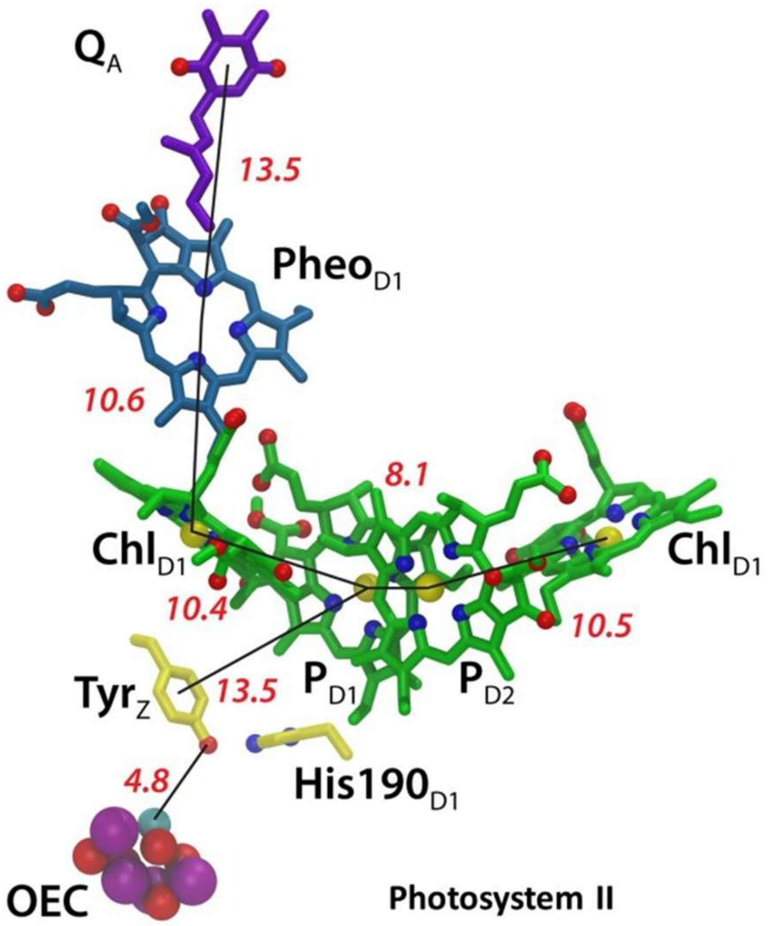
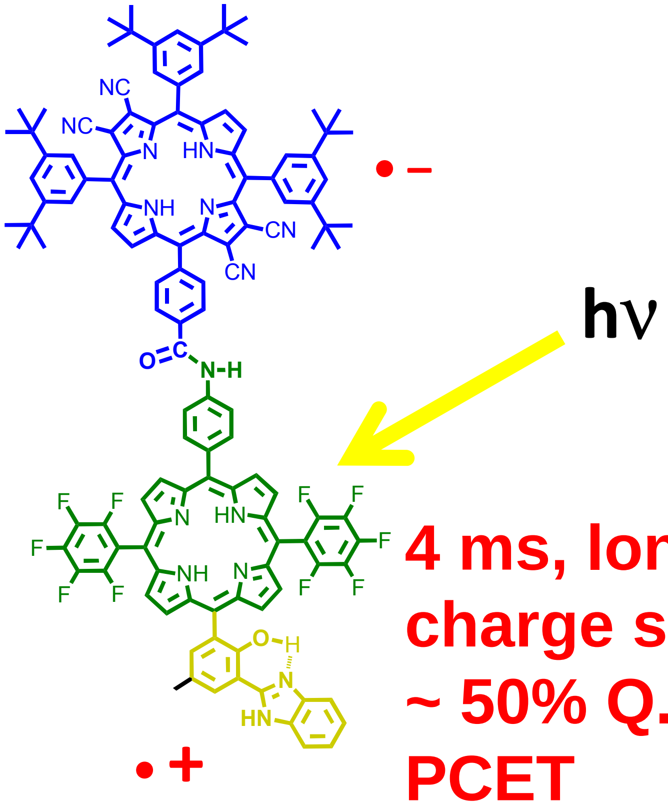
Artificial Photosystem II





4 ms, long lived charge separation
~ 50% Q.Y.
PCET

Megiatto *et al.* *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 15578.

The long lifetime of the highly oxidizing relay provides a good match for the slow kinetics of the OEC or metal oxide catalysts.

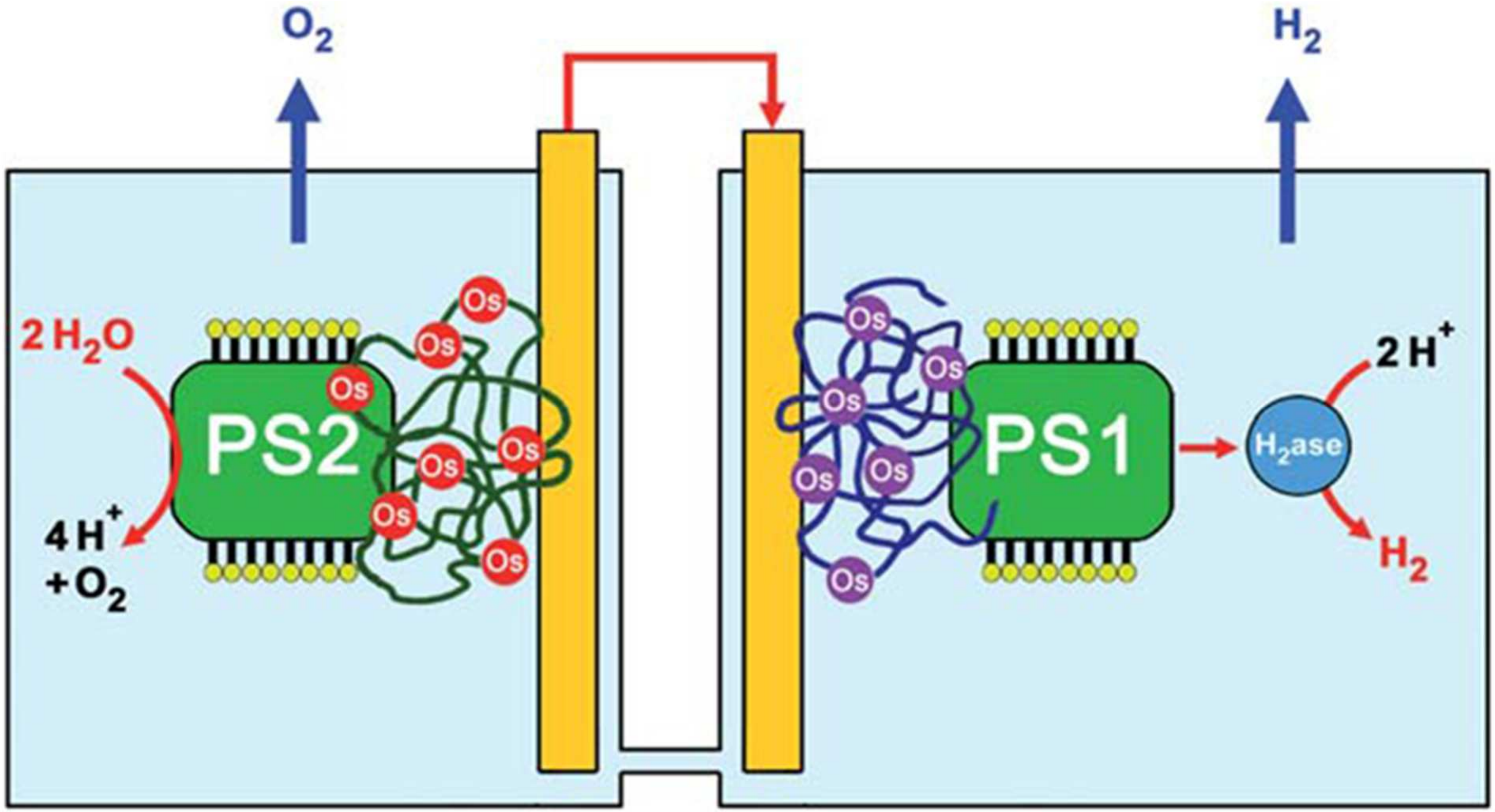
Artificial Photosynthesis

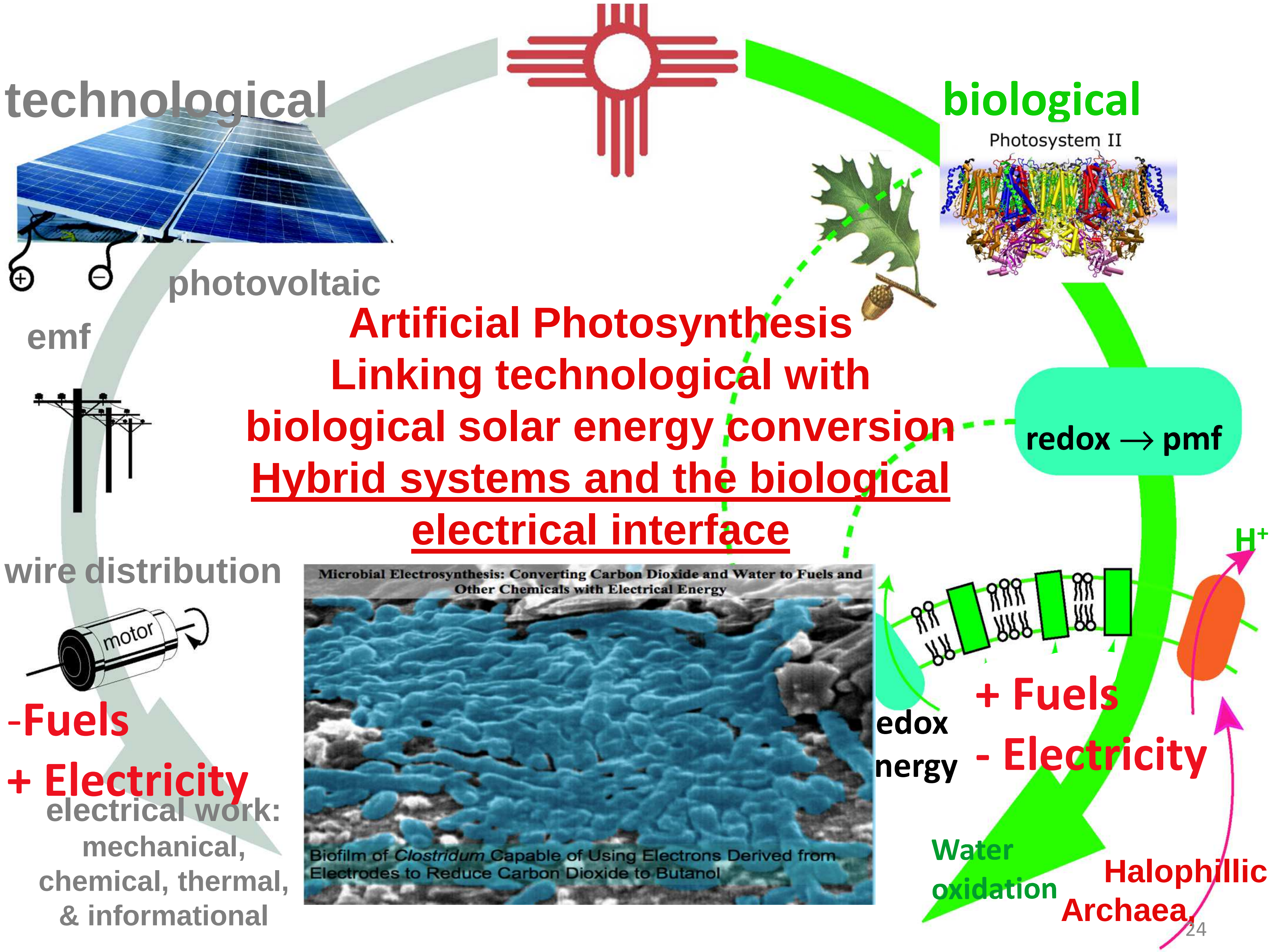
1. *The artificial leaf*
2. **The bio-hybrid device**
3. *The photosynthetic ‘solar fuel cow’*
4. *Improving natural photosynthesis*

Wiring photosynthetic enzymes to electrodes†

Adrian Badura, Tim Kothe, Wolfgang Schuhmann and Matthias Rögner

DOI: 10.1039/c1ee01285a





technological
biological
Photosystem II
photovoltaic
emf
Artificial Photosynthesis
Linking technological with
biological solar energy conversion
Hybrid systems and the biological
electrical interface
redox → pmf
wire distribution
Microbial Electrosynthesis: Converting Carbon Dioxide and Water to Fuels and Other Chemicals with Electrical Energy
Biofilm of Clostridum Capable of Using Electrons Derived from Electrodes to Reduce Carbon Dioxide to Butanol
motor
-Fuels
+ Electricity
electrical work:
mechanical,
chemical, thermal,
& informational
H+
edox
nergy
+ Fuels
- Electricity
Water
oxidation
Halophillic
Archaea

Artificial Photosynthesis

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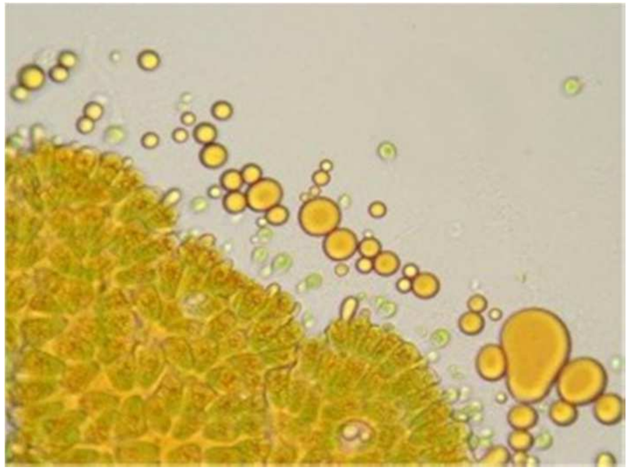
Algae and cyanobacteria for biofuel production

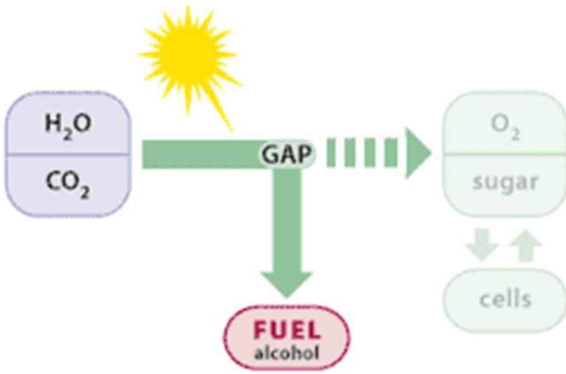
Advantages:
easy to grow
Use of salt water

No competition for land with food

Semi-productive levels (high value products, optimization of fuel productions, …



'Photofermenting' bacteria



Synthetic biology (new metabolic pathways leading to fuel)

MIX Photosynthesis with Fermentation

PHOTO

CO_2

GAP

Sugar-P

FERMENTATION

Sugar-P

GAP

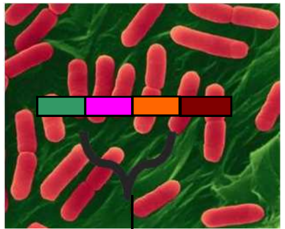
ethanol
butanol
propanediol
lactic acid

OPLOSSING:

ALGEN – CYANO's

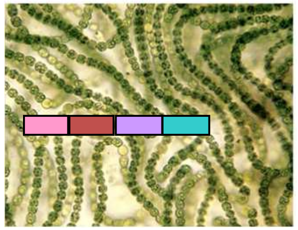
Photanol®, concept (2007)

Fermenting bacteria



DNA coding for fermentation

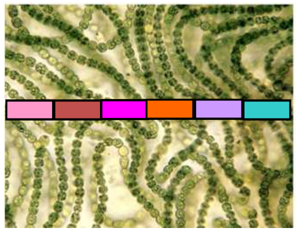
Photosythetic bacteria



Gentransfer to

Cyano bacteria (Blue green algae)

Photofermenting bacteria



Artificial Photosynthesis

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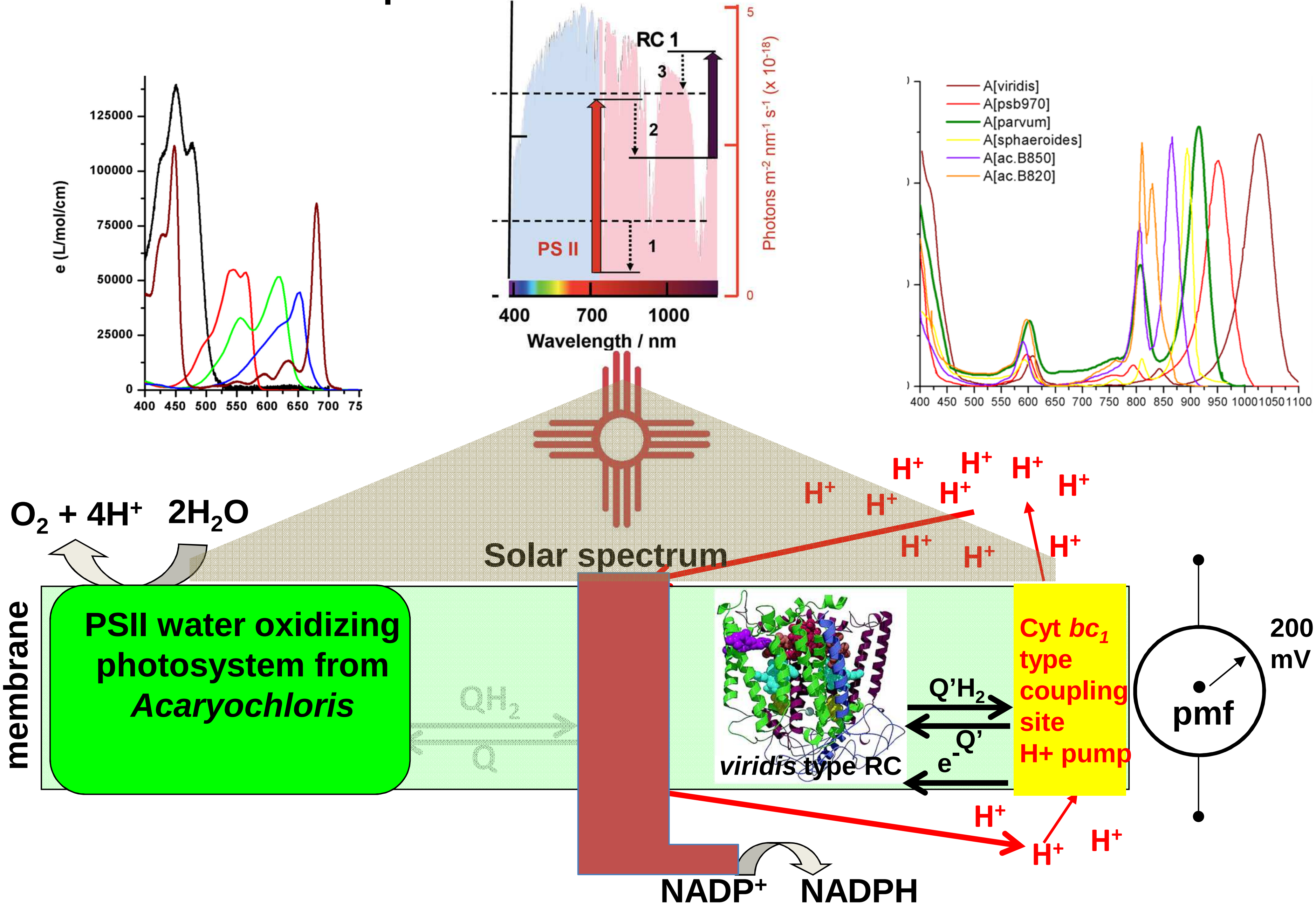
4. **Improving natural photosynthesis**

Directing the flow of energy in a reengineered photosynthetic membrane with true tandem cell performance



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