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Artificial Photosynthesis with Biomimetic Nanomaterials: Self-Repairing Solar Cells

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Current Photovoltaic & Photo-electrochemical Technologies

- Solar radiation: 120,000 TW constantly strikes the surface of the earth
- Presently, solar energy supplies less than 0.01% of world's energy demand
- Major challenge in solar energy utilization:

  Energy harvesting economically competing with cheap fossil fuel

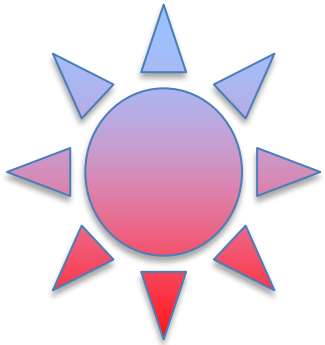
Type of Cell	Cell Efficiency	Current Technology Needs
Single-crystalline Si	24 %	Higher production yields, lowering of cost and energy content
Multi-crystalline Si	18 %	Lower manufacturing cost and complexity
Amorphous Si	13 %	Lower production costs, increase production volume and stability
Dye-sensitized solar cells	10 – 12 %	Improve overall efficiency and lifetime via system regeneration
Organic solar cells	6 – 7 %	Improve system stability and efficiency significantly

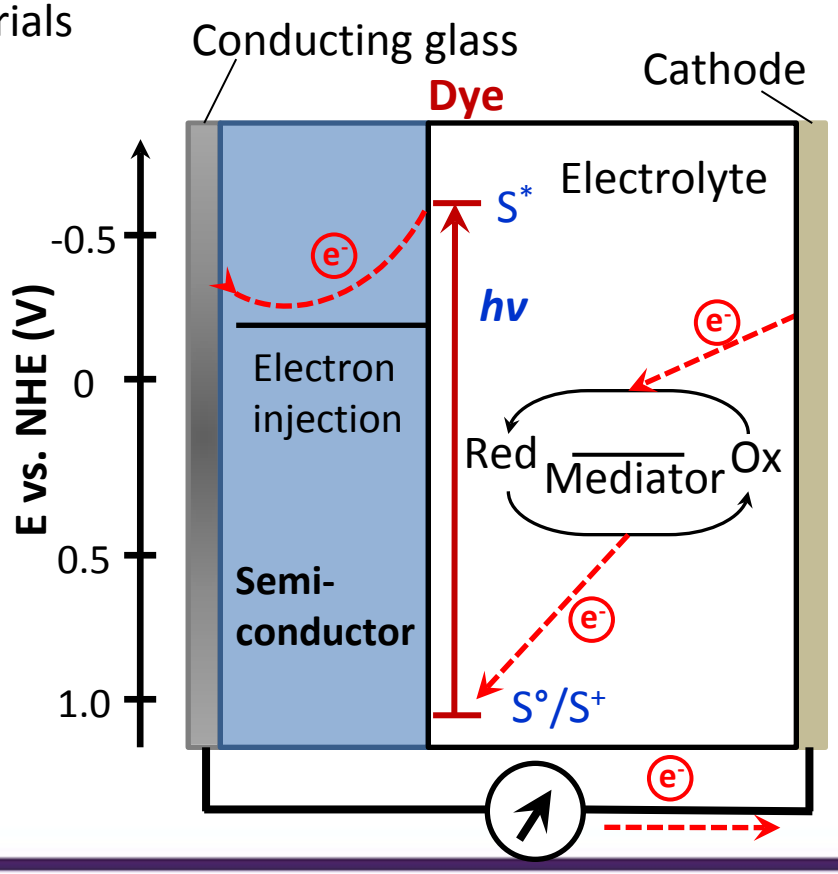
Lewis, *PNAS* (2006)
Kamat, *JPC* (2007)
Gratzel, *Nature* (2001)

One of the key drawbacks of Dye-sensitized solar cells:
Decrease in the system performance over time due to photo-induced damage of dye

Electrochemical Photovoltaic Cells

- Electrodes: ITO as WE and Pt as CE
- Electrolyte solutions
- Light absorbing dye: Ru compounds, porphyrin derivatives, etc
- Semiconductor nanomaterials





Gratzel, *JPPC PR* (2003)

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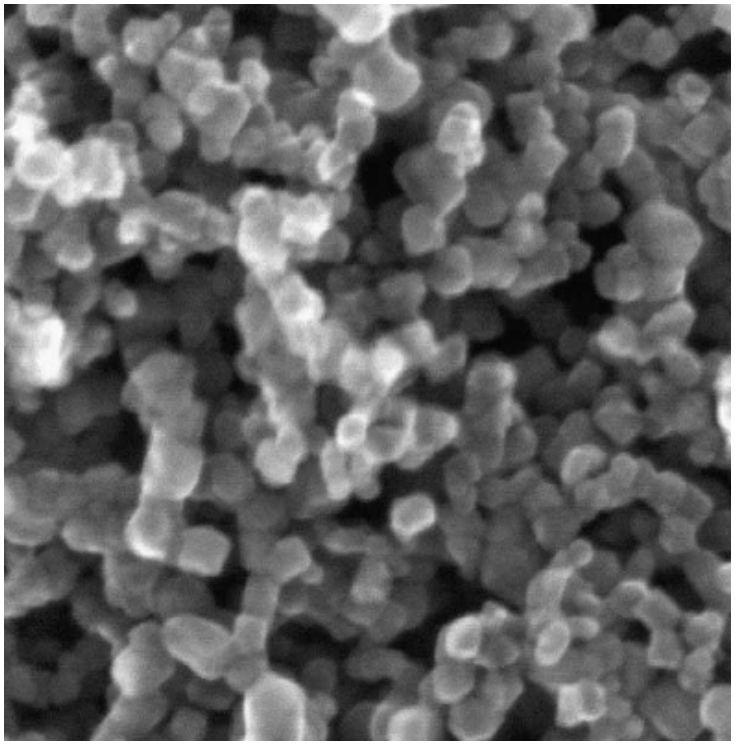


Currently:
Nanostructured materials provide high surface areas for energy conversion

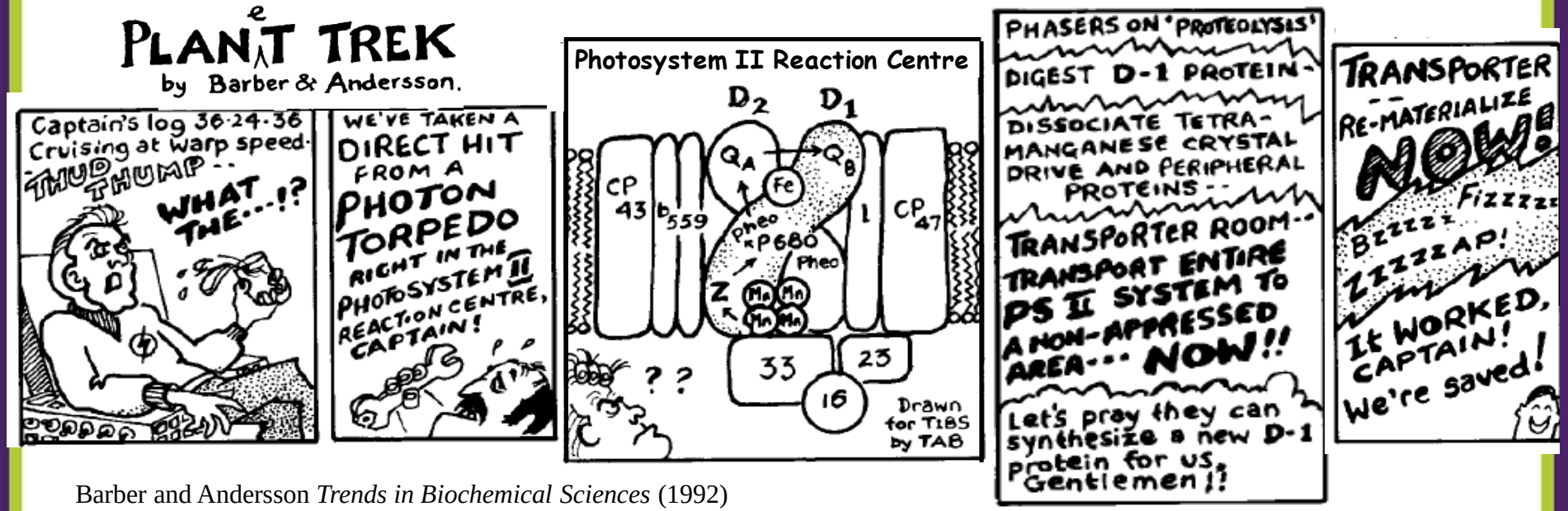
Problems:
Invariably static structures are unable to cope with degradation of dye molecules over time

Solutions:
We draw inspiration from natural photosynthesis, where structurally flexible systems self regenerate to improve overall efficiency and lifetime

Self-Repair in Natural Photosynthesis

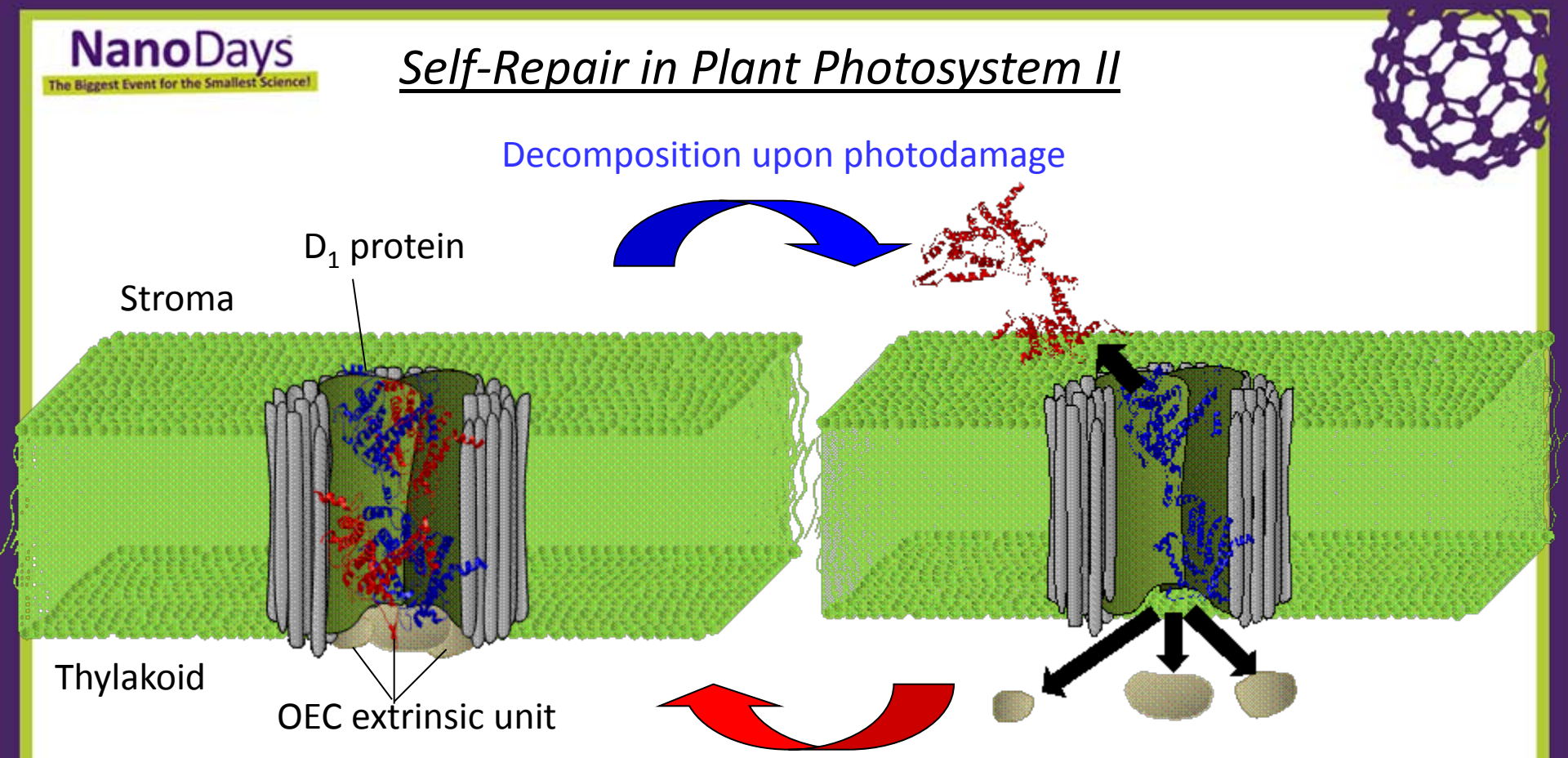
- Nature uses rapid and facile mechanisms of self repair that enable energy harvesting under conditions of photo-induced damage or degradation
- Photo-damaged components (i.e. D_1 protein) in the reaction center are constantly replaced – every hour

There is no such self generative analog in the synthetic realm !



Barber and Andersson *Trends in Biochemical Sciences* (1992)

Self-Repair in Plant Photosystem II



This natural self repair process relies on:

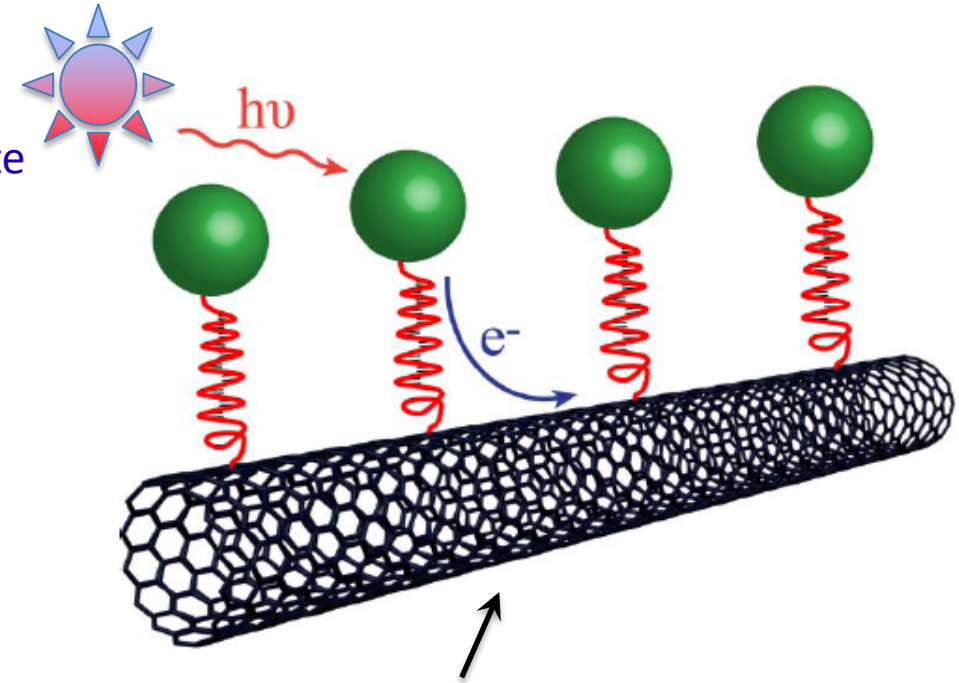
- Molecular recognition and Thermodynamic meta-stability
- Self assembly processes that can be reversed

Artificial Photosystems

We mimic photosynthesis processes by reversibly assembling carbon nanotubes and photosynthetic reaction centers that are capable of self-repair.

Photosynthetic proteins that generate electron from solar radiation
- extracted from purple bacteria

Rhodobacter sphaeroids



Carbon nanotube as a molecular wire

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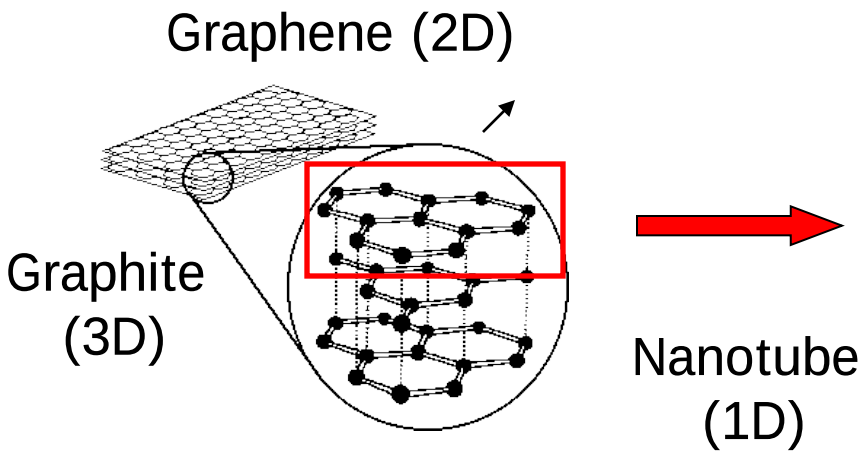
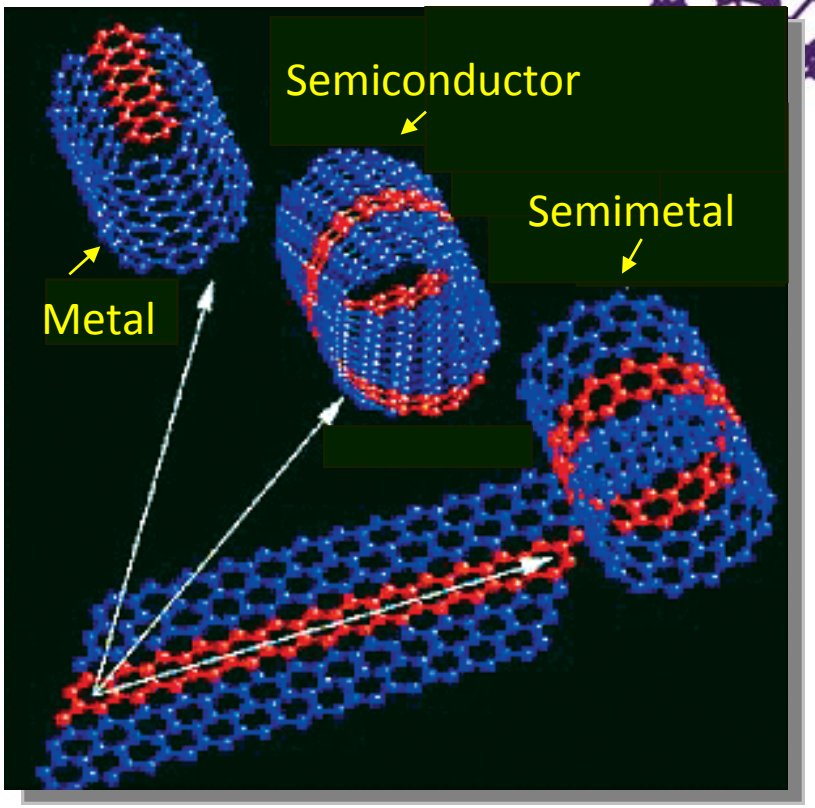
What is a Carbon Nanotube?

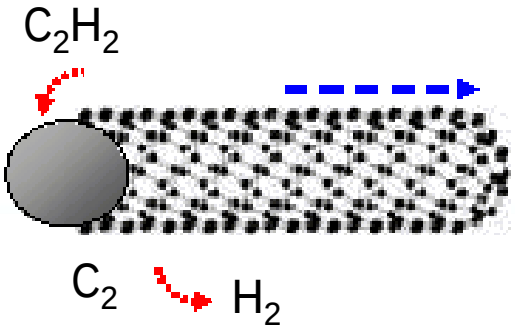


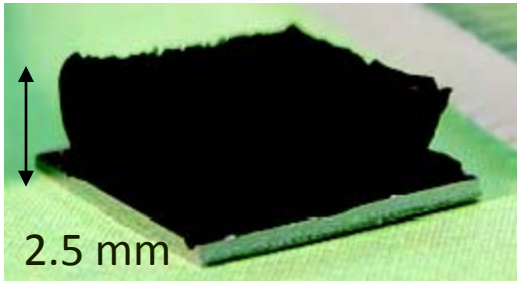


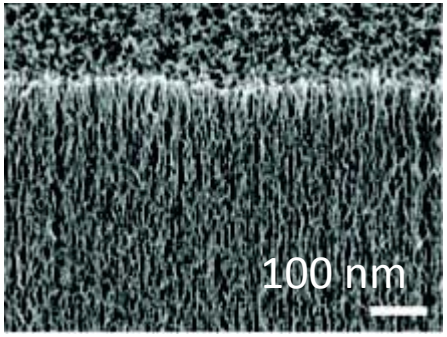
Electrons restricted to single dimension
Diameter ~1 nm

Synthesis

Chemical vapor deposition
Over metal (Fe, Co, Mo) nanoparticle





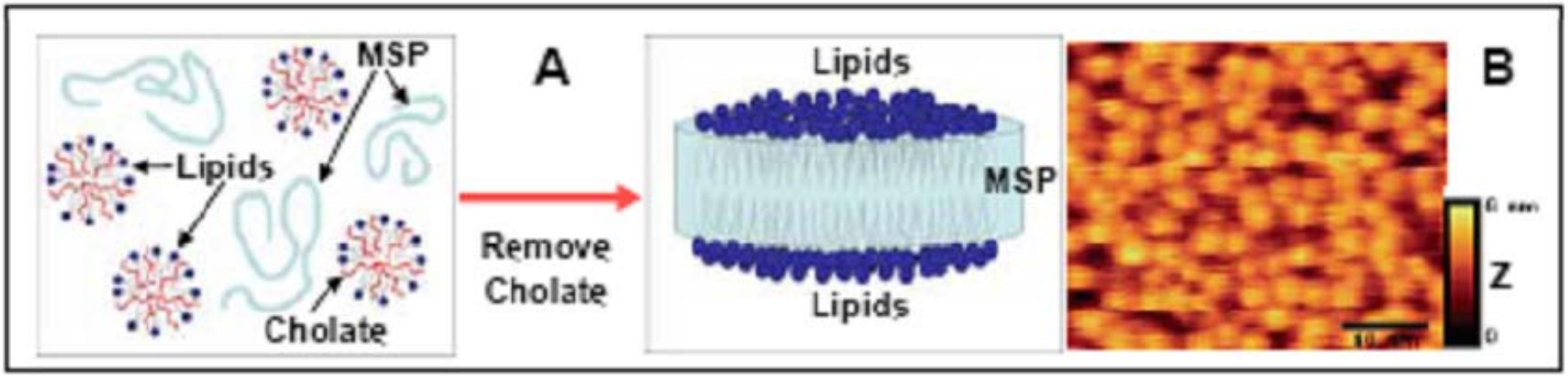


Length can range from 10 nm to 1 cm

Hata, K., Science 306, (2004), 1362

Mimicking Plant Cell Membrane – Lipid Nanodisc

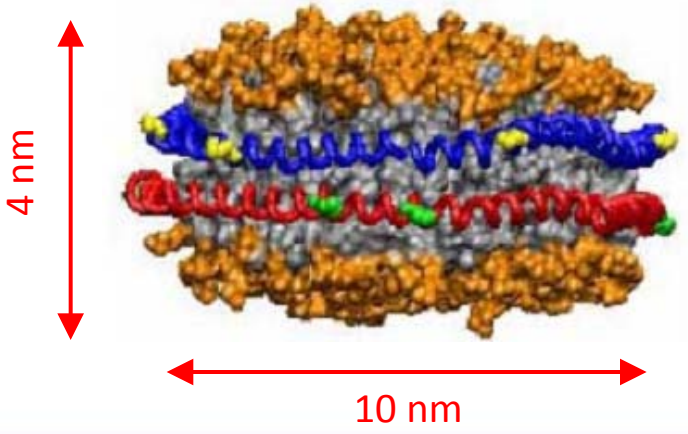
Nanodisc formation for protein reconstitution



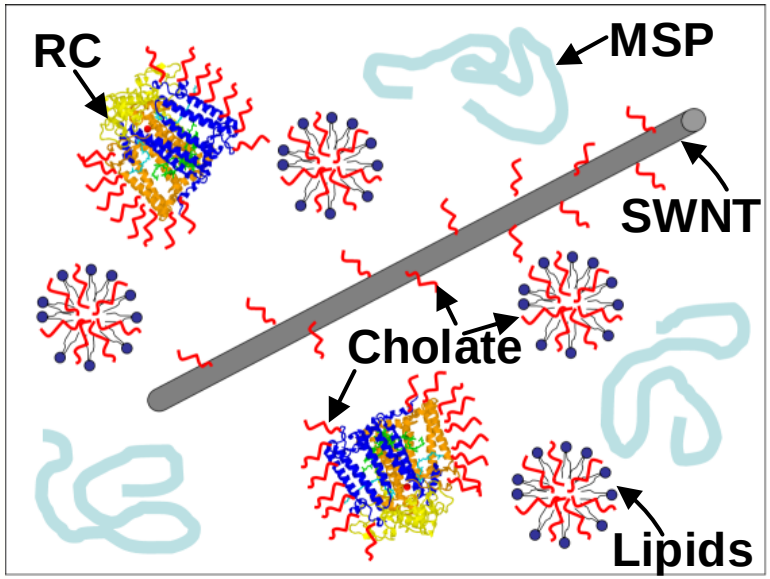
System initially stabilized with surfactant: sodium cholate

Sligar et al. *Nano Lett.* (2006)

- Phospholipids and Membrane scaffold protein (MSP) → Nanometer-sized discs
- Spontaneous self-assembly upon surfactant removal (cholate)
- Platform for suspending membrane proteins (i.e., photosynthetic reaction center or RC)

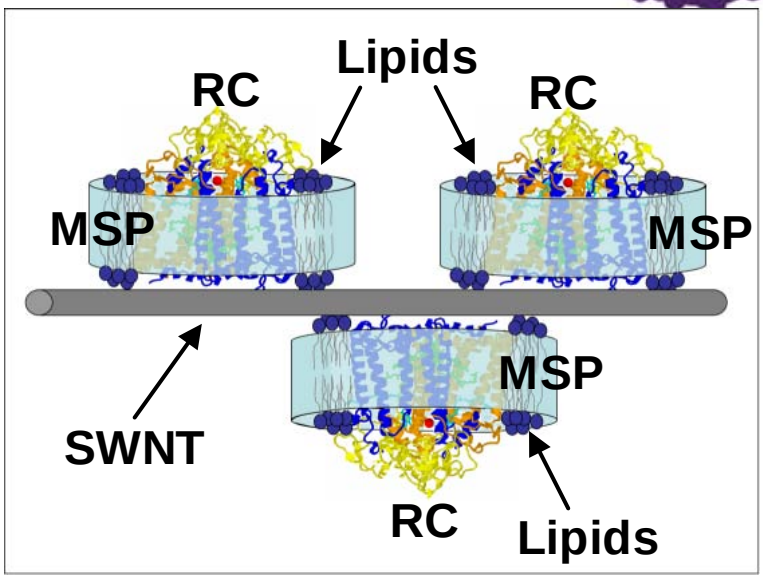


Reversible Self Assembly



Surfactant removal

Surfactant addition

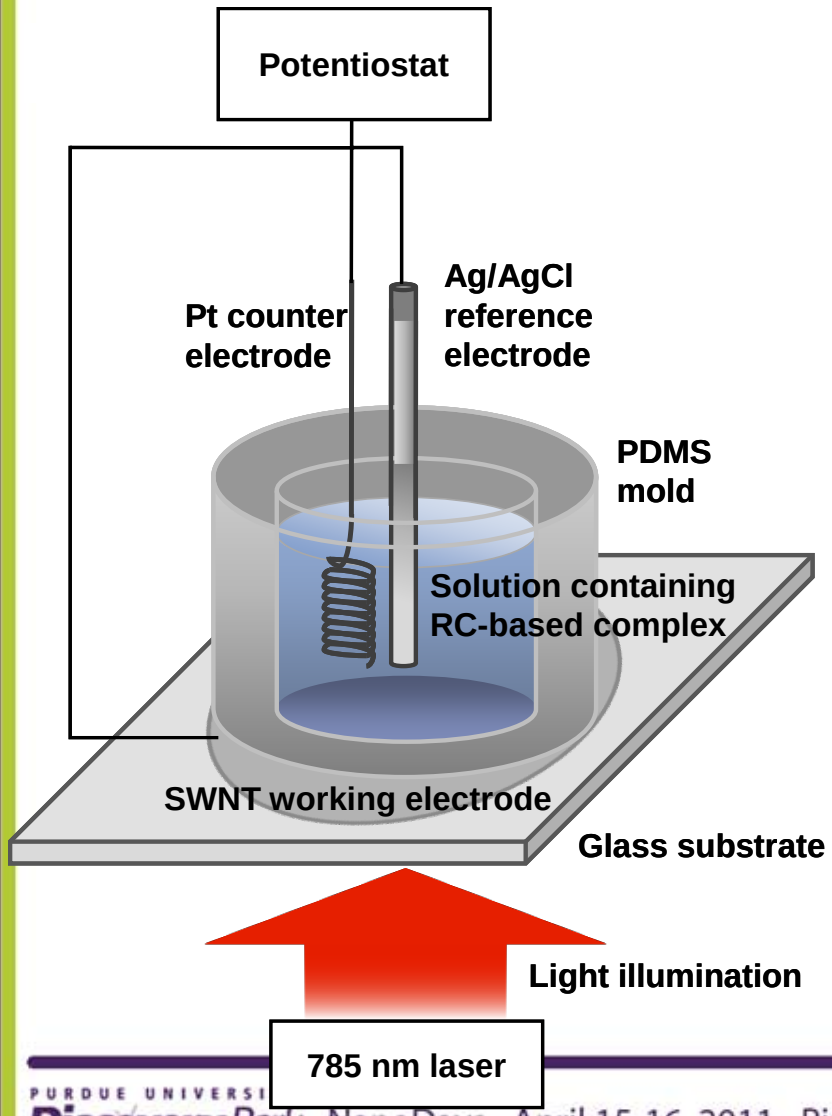


- Photosynthetic reaction centers (RC) isolated from purple bacterium, *Rhodobacter Sphaeroides*
- Nanodiscs reconstitutes RC, while suspending SWNT
- It could be the basis of light-harvesting devices with infinite lifetime
- Molecular recognition and thermodynamic meta-stability, just like molecular assembly in plants

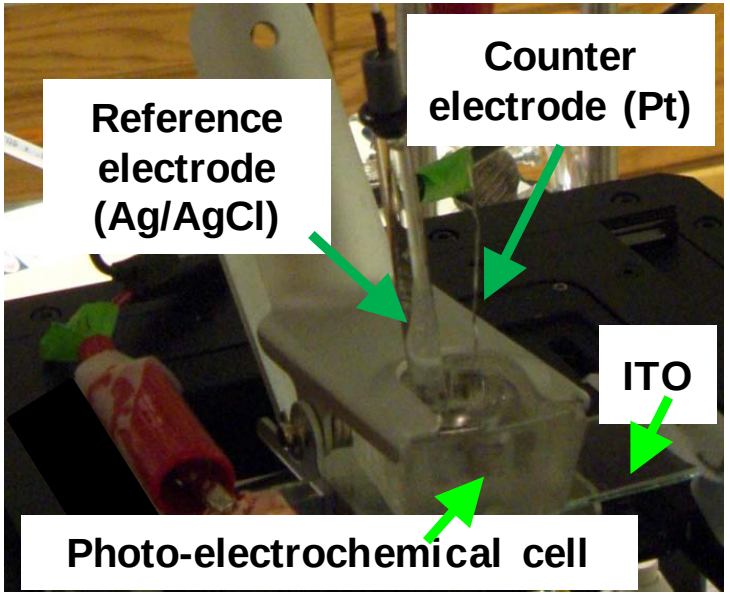
Ham, Choi et al. *Nature Chemistry* (2010)

Electrochemical Photovoltaic Cell

Photoelectrochemical measurement



Photocurrent generation



Double redox mediator system:

- Ubiquinone / ubiquinol
- Ferri- & ferro-cyanide: $Fe(CN)_6^{-3/-4}$

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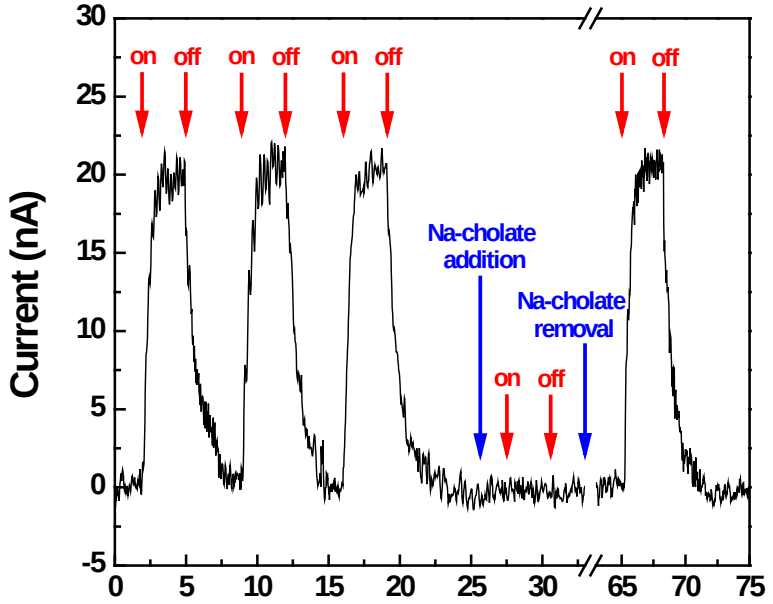
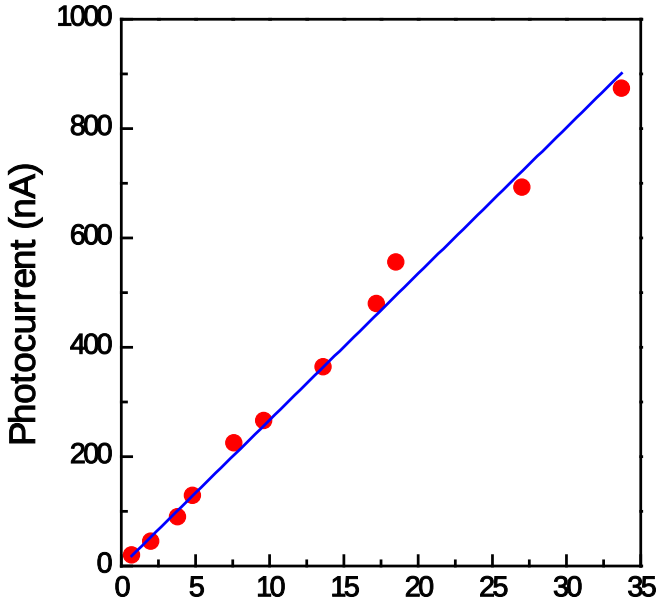
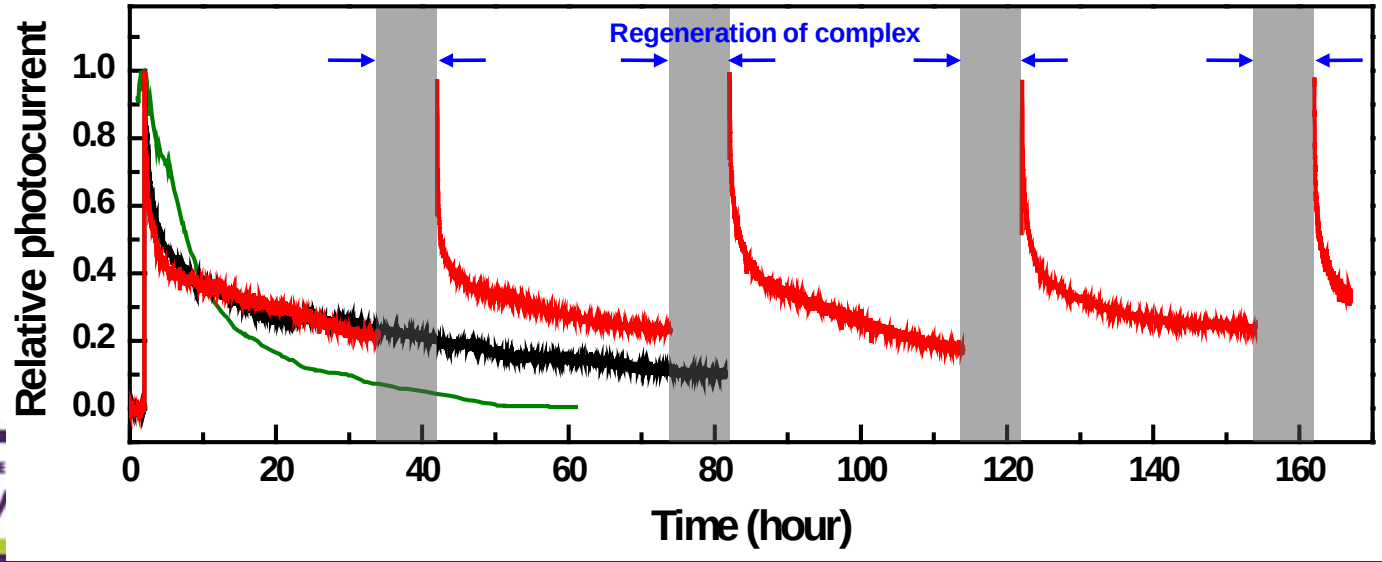
Photocurrent Generation via Light Harvesting





Chemically-initiated self-regeneration during light harvesting



Ham, Choi et al.
Nature Chemistry
(2010)

PURDUE UNIVERSITY Discovery

NISE network
NANOSCALE INFORMAL SCIENCE EDUCATION

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Acknowledgements

Graduate students

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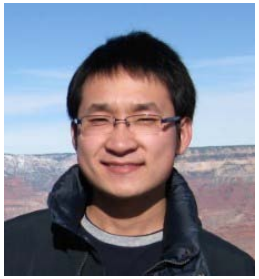

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