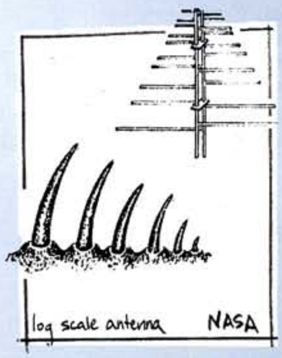
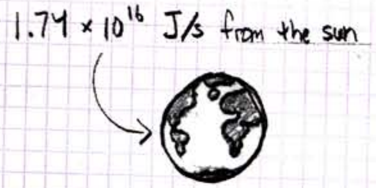
Biological Metaphors in Alternative Energy

Sean White sheds light on a biomimetic approach to solar cell and fuel cell design.

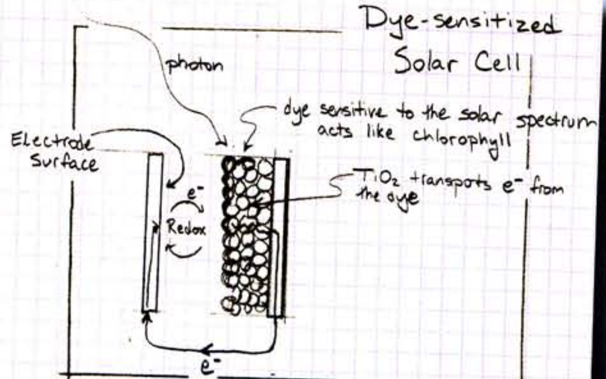
INSPIRATION. I've often looked to nature for insight and inspiration, but recently I've discovered the power of biology as a design approach. A few years ago, I wanted to know whether we could design an antenna for sunlight, to capture the light energy from the sun in the way radio antennas capture energy from electromagnetic waves at radio frequencies. After all, our eyes already act as feelers for such waves, so some similar interaction might be possible. After some research, I found a report published by NASA in 1975 on Electromagnetic Wave Energy Conversion written by two electrical engineers and an entomologist. The report is filled with classical EM analysis and, most significantly, pictures of insect antennae that form the basis for modeling small antennae for harvesting light. The authors gained their insight from studying the biological world.

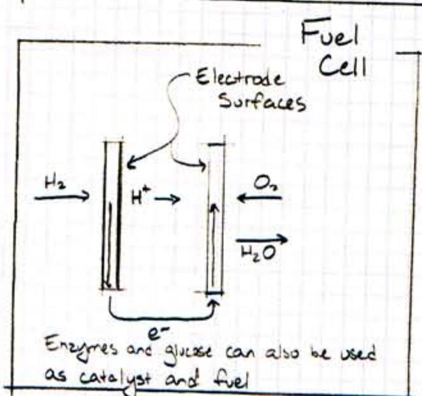


Drawing from "Electromagnetic Wave Energy Conversion Research", by Bailey, R.L., Callahan, P.S., 1975

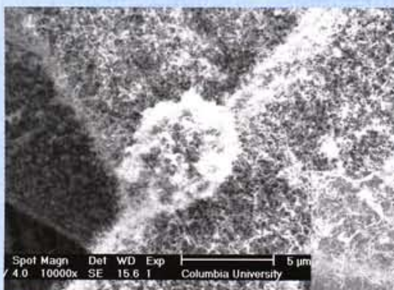


SOLAR CELLS and FUEL CELLS. At Columbia University, we've been applying the same approach to dye-sensitized solar cells (DSC) and fuel cells. The DSC, invented by Michael Graetzel, is a solar energy conversion system inspired by the photosynthetic process of plants. Much like how a leaf captures and converts light into energy using chlorophyll across a large surface area, the DSC uses dye across a large surface area to absorb photon energy, and a porous conductive network to transport the electron through the system. Good transport helps the electrons travel easily through the system and greater surface area means more sites for absorbing light and electrochemical reactions. At the same time, we've been working on a fuel cell that has similar transport and surface area issues around the electrodes.

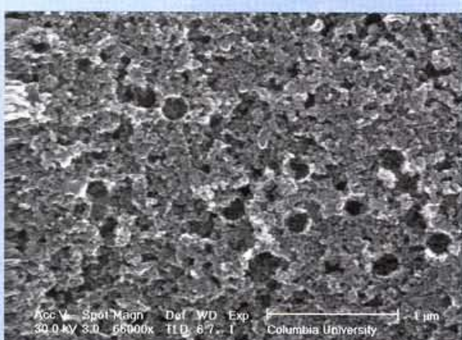




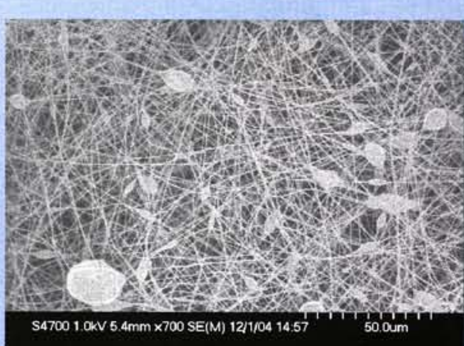
BIOLOGY. Nature addresses the problem of high surface area with transport in many clever ways. For instance, the human vascular system needs to transfer waste and nutrients to and from the blood stream. To do so, it transports blood to every nook and cranny of the body, providing as much surface area as possible in order to increase sites for transfer. We can imagine this as a multi-scale highway. This type system can be found elsewhere: the branches, flowers and roots of a tree or plant serve the same purpose.

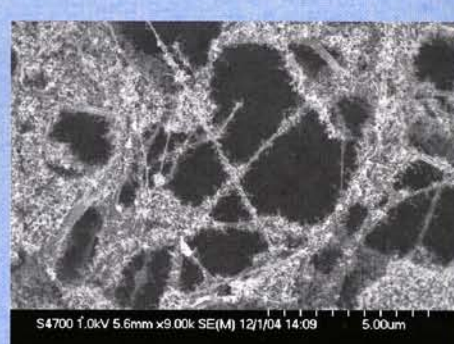


High surface area clusters in carbon nanotubes (left) resemble common biological forms such as flowering trees (top).



FROM METAPHOR TO MODEL. For the fuel cell, we've been experimenting with replicating this multi-scale vascular system by using multi-scale electrodes constructed from carbon fiber paper (10 microns), electrospun carbon fiber (500 nm) and carbon nanotubes (20 nm). They're all made of carbon so they provide good electron transport (graphite has a very low resistivity around 10 micro-ohm-meters). The results look promising. For the DSC, we're looking at similar changes to the electrode, and ways in which the surface area can provide enhanced light absorption through multi-scale porosity. As we look at the world around us, good ideas keep sprouting.





Multiple porosity scales are present in TiO_2 (top), electrospun fiber (far left), and carbon nanotubes on electrospun carbon fiber on carbon paper (left).

Photos courtesy of Columbia University.

This research was done in collaboration with Jim Hone, Scott Barton, Jessika Trancik, Yuhao Sun, and Adam Hurst.