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Power Plants: Engineers Mimic Photosynthesis to Harvest Light Energy

Theoretical models suggest ways for optimizing artificial photosynthesis to turn light into energy the way plants do

By Alison Snyder | Monday, December 13, 2010

LIGHT EFFICIENCY: Chemists are working to understand the efficiency with which plants harvest sunlight so that they can capture more of it with artificial systems. Image: Photo by Michael Gil, courtesy Flick

Plants take advantage of quantum mechanics to harvest sunlight with near-perfect efficiency—though only roughly 2 percent of that capture sunlight ultimately gets stored as chemical energy. Now scientists are studying how this light-harvesting step of photosynthesis is optimized by nature to learn how to mimic it in engineered systems for use in solar cells or artificial leaves that produce fuels directly from the sun**.**

Plants rely on chromophores—molecules that absorb certain wavelengths of visible light while reflecting others—to harvest energy from the sun. When sunlight hits a plant, electrons in the topmost chromophores absorb energy from incoming photons and then transfer it from the newly energized molecule to another molecule at a lower energy state. That transfer repeats itself via a chain of molecules, a cascade of rapid energy pass-offs that ultimately separates an electron from the last chromophore in the chain, which provides energy that is stored by the plant as a carbohydrate.

In this way chromophores perform three functions: they absorb energy from sunlight (acting as "acceptors"); they donate the energy they absorbed (as "donors"); and they transfer energy to another molecule (as "bridges"). Using measurements from other researchers of the intensity of photons absorbed and emitted by chromophores, chemist Jianshu Cao and his colleagues at the Massachusetts Institute of Technology developed a computer model to arrive at the ratio of acceptors, donors and bridges that optimizes the efficiency of the light-harvesting step of photosynthesis.

The findings: there is an optimal ratio of 10 donors for each acceptor in order to efficiently transfer energy in a natural photosynthetic system with just those two chromophore functions. Adding bridges to an arrangement of donors and acceptors then further increases the efficiency of energy transfer, Cao says.

Chromophores are arranged in bundles in plant cells, and these structures and configurations influence light-harvesting efficiency as well. University of California, Berkeley, chemist Matt Francis created artificial light-harvesting systems by attaching chromophores to tobacco mosaic virus molecules. Modeling these genetically engineered systems, Cao found that one structure—stacks of chromophore disks—could be tuned to improve the overall efficiency by combining multiple disks of similar size but different combinations of bridges, acceptors and donors. One particular configuration of two disks comprising bridges and acceptors stacked between disks made entirely of donors is a good candidate for designing artificial light-harvesting devices, according to the study published October 21 in *The Journal of Physical Chemistry B.*

Earlier research found that photosynthesis takes advantage of an effect known as quantum coherence. In one study researchers found that the energy absorbed by a chromophore travels through multiple networks at the same time in order to take the quickest path. Other research observed that "noise," or random fluctuations, at the quantum level helps move energy from chromophores to the reaction centers of photosynthesis. Building on this work, Cao and M.I.T. chemist Robert Silbey modeled a light-harvesting system in green sulfur bacteria and found that photosynthesis is most efficient when there is an intermediate amount of noise in the system. "In experimental conditions one always tries to reduce noise," Cao says, "but in a quantum mechanical system, it's actually useful to have some noise."

He offers the analogy of surface friction: If a car is on ice, without any friction it won't move at all. But if there is too much friction, a car also won't move. In photosynthetic systems an intermediate amount of random quantum fluctuations (think: friction) helps move the electrons carrying energy from one reaction center to the next, Silbey and Cao wrote in the October issue of the *New Journal of Physics*. By changing the temperature, strength and length of the random fluctuations in their models, they were able to optimize the energy transfer.

Engineering artificial systems like those involved in the light harvesting step of photosynthesis calls for a different design approach, says Seth Lloyd of M.I.T. and the Santa Fe Institute, who also works on quantum coherence in photosynthesis. "Natural selection is adding quantum design features and tuning them to the point where it is just complex enough to get the job done without compromising robustness." Engineers are often advised to keep it simple, but Lloyd says not too simple: "You want to have as many knobs that you can turn as functions you want to accomplish."