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New twist on life's power source

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A startling discovery by scientists at the Carnegie Institution puts a new twist on photosynthesis, arguably the most important biological process on Earth. Photosynthesis by plants, algae, and some bacteria supports nearly all living things by producing food from sunlight, and in the process these organisms release oxygen and absorb carbon dioxide.

But two studies by Arthur Grossman and colleagues reported in *Biochimica et Biophysica Acta* and *Limnology and Oceanography* suggest that certain marine microorganisms have evolved a way to break the rules—they get a significant proportion of their energy without a net release of oxygen or uptake of carbon dioxide. This discovery impacts not only scientists' basic understanding of photosynthesis, but importantly, it may also impact how microorganisms in the oceans affect rising levels of atmospheric carbon dioxide.

Grossman's team investigated photosynthesis in a marine Synechococcus, a form of photosynthetic bacteria called cyanobacteria (formerly blue-green algae). These single-celled organisms dominate phytoplankton populations over much of the world's oceans and are important contributors to global primary productivity. Grossman and his colleagues wanted to understand how Synechococcus could thrive in the iron-poor waters that cover large areas of the ocean, since certain activities of normal photosynthesis require high levels of iron. While others had suggested a potential role of oxygen as accepting electrons from the photosynthetic apparatus in place of carbon dioxide, the studies by Grossman's group show that this activity is significant in the oligotrophic (nutrient-poor) oceans, which cover about half the ocean's area.

“It seems that Synechococcus in the oligotrophic oceans has solved the iron problem, at least in part, by short-circuiting the standard photosynthetic process,” says Grossman. “Much of the time this organism bypasses stages in photosynthesis that require the most iron. As it turns out, these are also the stages in which carbon dioxide is taken from the atmosphere.”

“We realized very quickly that there was something different about the Synechococcus that we were studying” says Shaun Bailey, the lead postdoctoral fellow working on this project. “The uptake of carbon dioxide and the photosynthetic activities didn’t match, so we knew that something other than carbon dioxide was being consumed by photosynthesis, and it turned out to be oxygen.” The researchers have tentatively identified the enzyme involved in this process to be plastoquinol terminal oxidase, or PTOX. They point out that this new process must be considered in understanding the net primary productivity attributed to open ocean ecosystems.

During normal photosynthesis, light energy splits water molecules. This releases oxygen and provides electrons which are then used to “fix” carbon dioxide from the atmosphere and manufacture energy-rich molecules, such as sugars. In the newly discovered process, a large proportion of these electrons are not used to fix carbon dioxide, but instead go to putting the water molecules back together, which results in much less net oxygen production.

“It might seem like the cells are just doing a futile light-driven water-to-water cycle,” says Bailey. “But this is not really true since this novel cycle is also a way of using sunlight to produce energy, while protecting the photosynthetic apparatus from damage that can be caused by the absorption of light.”

Capturing energy by a light-driven water-to-water cycle is critical since marine cyanobacteria are constantly using energy to acquire the meager supply of nutrients in their environment. Recently, this newly discovered phenomenon was shown to occur in nature by graduate student Kate Mackey, who made direct measurements of photosynthesis in field samples from the Atlantic and Pacific Oceans. “The low nutrient, low iron environments account for about half of the area of the world’s oceans, so they represent a large portion of the Earth’s surface available for photosynthesis,” says Mackey. “Our findings show that this novel cycle occurs in two major ocean basins and suggest that a substantial amount of energy from sunlight gets re-routed away from carbon fixation during photosynthesis. This may mean that less carbon dioxide is being removed from the atmosphere by the open ocean photosynthetic organisms than was previously believed.”

“This discovery represents a paradigm shift in our view of photosynthesis by organisms in the vast, nutrient-starved areas of the open ocean”, says Joe Berry of the Carnegie Institution’s Department of Global Ecology. “We had assumed that like higher plants, the goal was to make carbohydrates from carbon dioxide and store them for later use as a source of energy for any number of cellular functions or growth. We now know that some organisms short-circuit this complicated process, using light in a minimalist way to power cellular processes directly with a far simpler and cheaper (in terms of scarce nutrients such as iron) photosynthetic apparatus. We don't know the full significance of this finding yet, but it is certain to change the way we interpret optical measurements of photosynthetic pigments in the ocean and the way we model ocean productivity.”

Wolf Frommer, director of the Carnegie Institution’s Department of Plant Biology, agrees about the discovery’s ground-breaking importance. “If we thought we have understood photosynthesis, this study proves that there is much to be learned about these basic physiological processes.

The findings of Grossman's laboratory together with previous evidence reported by Greg Vanlerberghe from the University of Toronto showing that the gene encoding PTOX appears to be widespread in marine cyanobacteria will add depth and a mechanistic foundation for the modeling of primary productivity in the ocean."

Source: Carnegie Institution