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Protecting resources from oxygen damage

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Funded by the Department of Energy's Office of Science, scientists are devising ways to blunt reactive oxygen atoms' impact on producing biofuels. Credit: US Department of Energy

Vital to life on this planet, oxygen has a sinister and ravenous side that harms plants and biofuel production. That's why the Department of Energy's Office of Science supports research to tame oxygen's dark side.

For more than 2 billion years, oxygen from algae and later, trees, shrubs and other plants has spread across the planet and reacted with nearly everything. "Oxygen the element is common in the universe," said Stephen Herbert, who leads the Photosynthesis Systems program at the Department of Energy's Office of Science. "However, you don't usually see it as a gas, except on earth."

When the levels of this odorless, tasteless, colorless gas first began to climb, it rusted dissolved iron in the oceans. Then the gas began to build up and form the planet's protective ozone layer and, eventually, became the breathable atmosphere we know today.

Oxygen gas is involved in reactions all around you. It's vital in creating the energy that fuels cells in our bodies and in plants.

Protecting Nature's Photosynthesis Factories

Inside rose bushes and other green plants, photosynthesis relies on a complex clump of proteins called Photosystem II. These proteins are vital to the chain of reactions that take in water, carbon dioxide and sunlight to produce oxygen and energy—the reaction we know as photosynthesis

But if a plant gets too much light, that critical group of proteins pumps out reactive oxygen-containing molecules, such as hydrogen peroxide, a common fizzy antiseptic, that wreak havoc on the plant. Why this happens and how to stop it are questions that drove Terry Bricker at Louisiana State University and his colleagues to determine exactly how these reactive molecules work. Starting with spinach, the team isolated Photosystem II, the clump of proteins that produces the oxygen in our air. They exposed the cluster of proteins to a lot of sunlight, essentially giving it a sunburn. "It is only when it gets 'sunburnt' that it makes reactive oxygen molecules that can damage photosynthesis," Bricker said.

Bricker and his team found that the reactive oxygen molecules attack specific amino acid building blocks in Photosystem II. The oxygen attacks numerous amino acids if there is too much light, essentially paralyzing the protein and hampering plant growth.

That's a problem when it comes to growing biomass for fuels or crops to feed hungry people.

Knowing how the oxygen assaults plants could offer insights for building up nature's defenses. Researchers at Lawrence Berkeley National Laboratory in California and at the University of Illinois could help prevent oxygen damage in plants by stopping harmful reactions earlier in the process. They altered how the plants express certain genes, allowing for photosynthesis that is more efficient and avoiding harmful hydrogen peroxide and other molecules.

The team targeted a trio of genes, bits of genetic material that form a plant's chromosomes. These genes are involved in protecting plants from overexposure to sunlight. By boosting the expression of the genes, the team saw a 20 percent increase in plant growth without adding more water or fertilizer. "We thought this was impossible not that long ago," Herbert said. This proof that photosynthesis could be improved was supported by a $25 million grant from the Bill and Melinda Gates Foundation. Learning enough about oxygen and photosynthesis to design the improvement was supported by grants from the DOE Office of Science and other basic science funding over more than a decade.

Targeting the Troublemakers

When using plants to create fuels, cutting the right oxygen atoms from glucose, the sugary fuel resulting from photosynthesis, is challenging. The problem is that oxygen makes up roughly half of a glucose molecule. Scientists need to remove just the right oxygen atoms to make sure they get energy-dense fuels, not weak substitutes.

Removing the right atoms from glucose and creating a usable fuel or chemical precursor typically requires two reactions. Scientists remove an oxygen atom from glucose to create a chemical abbreviated HMF. They use a second reaction to remove another oxygen atom and create a slightly different molecule called DMF, and that's where it gets tricky. The materials that drive the reactions to create DMF can be aggressive. They don't stop when they've produced DMF. They take out more oxygen. They keep reacting and turn the DMF into unwanted products.

Researchers tried a different approach. Instead of trying to tame the one aggressive catalyst, the material that drives the reaction but isn't consumed by it, they gave it a partner in crime. Would adding a second Mr. Hyde add stability or chaos? Hinder or help?

The researchers wrapped a thin layer of cobalt around tiny particles of platinum. As the HMF flows through the catalyst, the cobalt hinders HMF's oxygen-containing ring, keeping it from reacting in unwanted ways. At the same time, however, cobalt "paints" targets on the HMF. Platinum homes in on the targets, removes the targeted oxygen atoms and creates the fuel DMF.

This mixture "was much more stable than either of the pure metals," said Raymond J. Gorte, professor at the University of Pennsylvania. Gorte and his colleagues are part of the Catalysis Center for Energy Innovation, an Energy Frontier Research Center funded by the DOE Office of Science and headquartered at the University of Delaware.

They are now looking at other combinations of metals that don't involve expensive, precious metals. "It's a catalyst waiting for a process that's commercially viable," Gorte said.

The Search for Understanding Continues

Knowing what drives oxygen's behavior is crucial to getting what we need, whether that's less waste when producing biofuels or better biofuel stock by managing photosynthesis. "If photosynthesis stops, all the oxygen in the atmosphere would be consumed by chemical reactions," Herbert said. "There would be nothing left to breathe." Photosynthesis is the Dr. Jekyll oxygen personality everyone wants at their Victorian dinner party. The trick for scientists, it appears, is to regain control of oxygen's rascally Mr. Hyde persona.

Provided by US Department of Energy