Turning up the light: Plants, semiconductors and fuel production

ASU professor researches how to create viable alternative to fossil-based fuels

By Jenny Green, ASU News
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What can plants and semiconductors teach us about fuel production?

ASU's Gary Moore hopes to find out.

With the aim of learning how to create viable alternatives to fossil-based fuels, Moore — an associate professor in the School of Molecular Sciences and a researcher in the Biodesign Center for Applied Structural Discovery — studies what plants and semiconductors can teach us about producing fuels from light.

The idea is that the capture, conversion and storage of solar energy in the form of chemical feedstocks has vast potential for revolutionizing the energy sector.

“The five 5 Cs — copper, cattle, cotton, citrus and climate — represent Arizona’s early economic foundation and are rooted in Arizona’s history. Chips, as in semiconductor chips, could become a new C for Arizona,” Moore says. “Our research group is investigating how illuminated semiconductors could power the production of fuels and fine chemicals.”

Moore’s group has recently published a study on solar-fuel-forming reactions, featured on the cover of the journal ACS Catalysis.

“Our work showcases how light can be used to produce fuels and how the intensity of illumination establishes the fuel-production rates and required energy inputs for improving efficiencies,” Moore says.

Ian Peterson, an undergraduate in the School of Molecular Sciences who contributed to this work, joined the Moore research group in early 2023 to study how the mechanisms of fuel-forming reactions change with reaction conditions. His work, a subject of the ACS Catalysis paper, explores hydrogen production using light-activated catalysts.

“Specifically, I worked with a system that combines a photovoltaic semiconductor for harvesting solar energy with a thin-film molecular coating that uses the captured energy to produce hydrogen,” Peterson explains. “The semiconductor is p-type gallium arsenide, and the molecular coating contains a cobalt-based complex encapsulated within a polymeric material.”

One of the main goals was to see how different colors of light and their brightness influence the rate of the hydrogen-fuel-forming reaction at the catalytic cobalt sites. The group’s results enabled them to develop a mathematical relationship equating the rate at which particles of light strike the surface of their molecular-modified semiconductors to the rate at which an individual cobalt site produces hydrogen.

Peterson goes on to explain a key discovery: At higher light intensities, and thus higher reaction rates, the chemical entities that are converted to hydrogen change. Under higher light intensities and reaction rates, water serves as the primary reactant for hydrogen production. However, at lower light intensities and reaction rates, buffering salts in the water are the dominant reactants for producing the hydrogen. Depending on the reaction conditions, the buffering salt concentrations or the light's intensity can limit the overall rates. A surprising finding was that the buffers can outcompete and react faster than water.

“Understanding this is important because it affects how we evaluate and design materials for solar-powered systems and where light intensity can play a key role in controlling reaction rates,” Peterson says.

Lillian Hensleigh, a graduate student, is co-author of the article. Other researchers from Moore’s group participating in this work include past graduate students Daiki Nishiori and Nghi Nguyen. Nishiori is now working with the Resonac Corporation in Japan, and Nguyen is working with Intel Corporation in the U.S.

“In addition to the scientific impacts, the research fosters active learning experiences for the students participating in this work and expands their career opportunities,” Moore says.

The work was supported by the U.S. Department of Energy Office of Science.

Harnessing the power of sunlight

A photon is a tiny particle of light that carries energy. The amount of energy depends on its color and whether it possesses, for example, ultraviolet, visible or infrared frequencies. Photochemistry involves the chemical effects of light, where reactions are usually caused by absorption of ultraviolet, visible-light or infrared radiation.

The photons Moore’s research team works with come from sunlight and are used to convert water and air into domestically produced, nonfossil-based fuels.

“Inspired by the process of photosynthesis, we can develop materials and processes to produce clean fuels as well as other commodity products,” Moore said.

In addition to studying solar energy conversion pathways, the design and synthesis of catalysts is also central to the research efforts of Moore and his team.

Catalysts provide low-energy pathways for carrying out a chemical transformation at a desired rate. For this reason, they are used in myriad industrial applications and are imperative to the bioenergetics of all living organisms.

A catalyst speeds up a chemical reaction by providing an alternative reaction pathway. Just like the catalytic converters in our vehicles, catalysts are not changed in any way by the reactions they are aiding.

Catalysts are essential to the effective performance of technological systems and all living organisms. However, "molecular scaling relationships" involving trade-offs between thermodynamic (energetic) and kinetic (rate) performance metrics limit their efficiency.

For example, the Sabatier principle indicates that optimal catalysis occurs when the binding between catalysts and their chemical substrates is "just right" and of intermediary strength. In other words, the interactions should be neither too strong nor too weak; otherwise, the binding of the reactants or desorption of the products will limit the reaction rate.

Moore and his group place a strong emphasis on developing effective methods for interfacing catalytic materials with those that harness solar energy. They also seek to better understand the relationships between the structure and function properties of the resulting architectures.

Moore will present his team's findings as an invited speaker at the 2025 Gordon Research Conference on Photochemistry, which provides "an international forum for the presentation and discussion of frontier research."

Moore is also a 2025 awardee of the Presidential Early Career Award for Scientists and Engineers — the highest honor bestowed by the U.S. government on early-career scientists and engineers.

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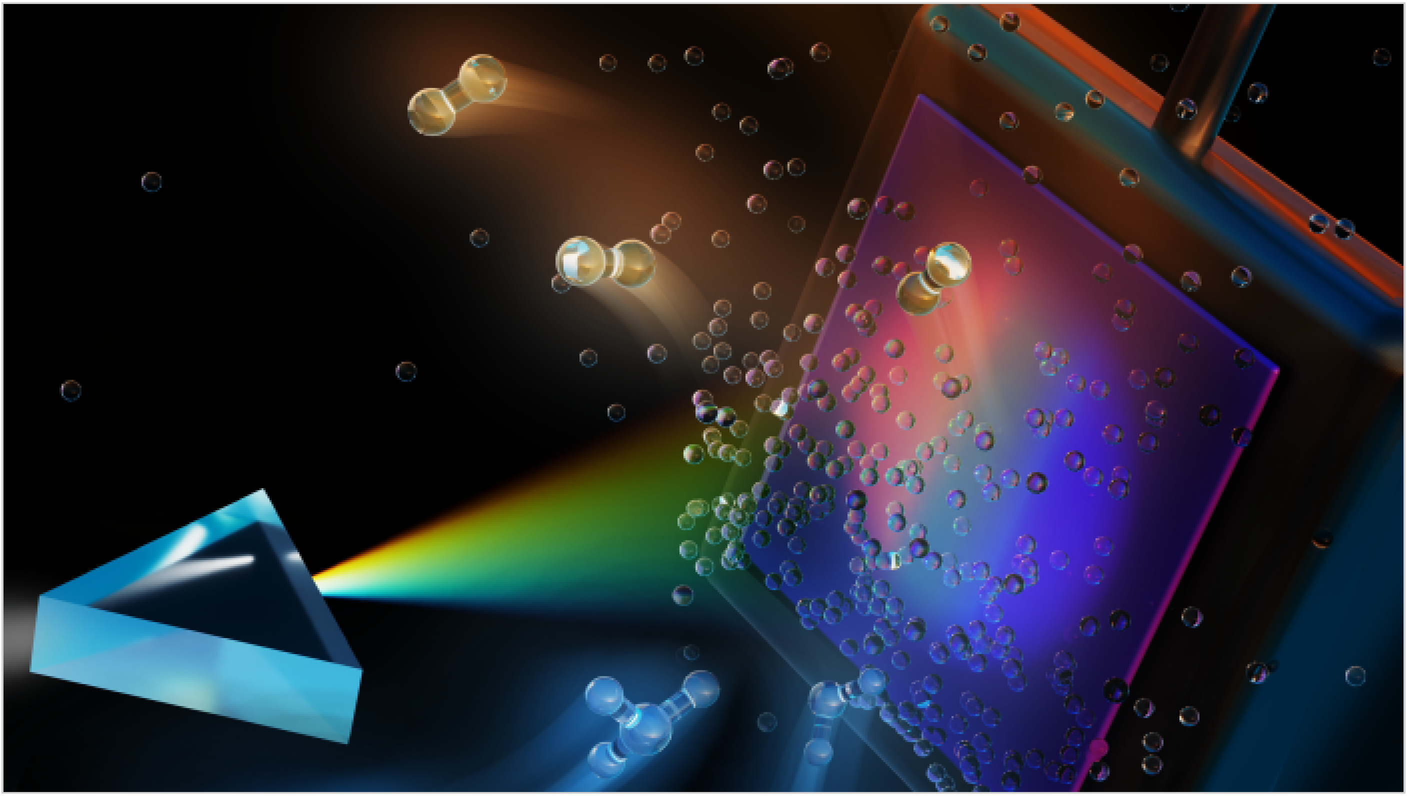
Main image



Artwork by Jason Drees depicts an approach for determining which colors of light contribute to hydrogen-fuel production on an illuminated semiconductor surface. The reactants for forming the fuel can include water, which is relatively slow to react, or buffers such as phosphate, which are more facile.

Text image(s)

Associate Professor Gary Moore. Photo by David Rozul/ASU