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Inspired by nature, researchers are exploring new ways to use sunlight and water to produce clean hydrogen. © icemanpho

Sunlight, water and a new, cleaner way to make green hydrogen

Inspired by nature, EU-funded researchers have developed a system that uses sunlight and water to produce green hydrogen, potentially opening a new route to producing and storing renewable energy locally.

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Plants have been doing something remarkably sophisticated for hundreds of millions of years. By capturing sunlight, leaves convert its energy into chemical energy that can be stored and used later.

Inspired by this natural process, a team of European researchers has spent nearly four years developing a system that uses sunlight to split water, producing green hydrogen that can be stored and used later as an energy source.

For Dr Ailbe Ó Manacháin, a senior scientist at University College Cork in Ireland who led the research, the starting point was a deceptively simple question: could sunlight be converted directly into green hydrogen through a single, reusable, carbon-free multicell system?

The work, carried out through the EU-funded FreeHydroCells project, brought together researchers from Ireland, France, Germany and Italy.

“We wanted to develop a more efficient and cost-effective way of generating clean energy by taking inspiration from how leaves capture sunlight,” he said.

Sunlight to hydrogen

Hydrogen is expected to play an important role in Europe’s transition away from fossil fuels.

But producing hydrogen using renewable energy is not straightforward. The conventional approach to so-called green hydrogen is to use renewable electricity to power an electrolyser, which then splits water into hydrogen and oxygen. This requires separate systems to generate the electricity and split the water.

The FreeHydroCells researchers explored a more integrated approach, bringing those functions together in a single system. Starting with new semiconductor materials that were still at an early stage of development, they set out to build a complete system that could split water into hydrogen and oxygen using sunlight, without relying on fossil fuels.

To do this, they wanted to combine efficiency, affordability and durability, while using materials that are abundant and sustainable. They also wanted to show that the technology could be scaled up, moving from

small cells to larger ones, and eventually bringing them together in a single working multicell system.

Leaf-like process

The researchers describe their technology as ‘leaf-like’, rather than an artificial copy of photosynthesis. A natural leaf uses sunlight, water and CO_2 to produce organic matter in which energy is stored. The FreeHydroCells system instead uses sunlight to drive a carbon-free process that splits water into hydrogen and oxygen.

“In the end, a leaf is also a solar-powered biochemical factory,” said Dr Ulrich Plachetka, who leads research groups in sensor technology and energy conversion at German nanotechnology research organisation AMO, based in Aachen.

At the heart of the system are thin layers of semiconductor materials designed to absorb sunlight. When sufficient light energy is absorbed, it generates electrical charges that can be transferred to interfaces with water, providing the energy needed to split the water molecules.

In other words, sunlight is captured and converted into chemical energy in the form of hydrogen – within the same overall system.

From a cell to a system

The concept is not entirely new. Photoelectrochemical cells have been studied for over five decades, but turning the idea into a practical technology presents a much bigger challenge.

The researchers had to bring together different areas of expertise, including semiconductor materials, nanotechnology, water splitting and energy conversion. They also needed to address some fundamental practical questions. Could the technology work over a larger area? Could the different components be integrated? And could the resulting system be made using manufacturing-compatible processes?

Over several years, the team moved from newly emerging semiconductor materials and small laboratory cells towards larger area multilayer cells and, ultimately, a multicell water splitting system.

This system-level achievement is an important part of the project’s results. Rather than demonstrating only an individual working cell, the researchers have integrated multiple components into a larger system designed with eventual manufacturing in mind.

Tests under simulated sunlight demonstrated solar-to-hydrogen efficiencies of around 18–21%, a strong result for direct solar water-splitting systems. Unlike conventional electrolysers, which first require electricity to be generated and then use it to split water, the system operated without an external electrical bias, using captured sunlight directly.

The technology is still at technology readiness level 4 (TRL 4), meaning it is in an early testing phase and not a product ready for commercial use. But for the researchers, demonstrating that the different elements can work together over a large area was a significant step.

Making clean hydrogen more accessible

For the research team, however, efficiency alone is not enough. For green hydrogen to become a practical alternative to fossil fuels, it also needs to be affordable and durable, while avoiding dependence on scarce materials. The FreeHydroCells system uses thin film technologies, as well as abundant, sustainable and potentially recyclable materials.

The researchers have developed larger area, lightweight components that could eventually be combined into modular systems. This points towards a different way of producing and storing energy. Rather than relying entirely on large, centralised facilities, hydrogen could potentially be produced closer to where it is needed.

In the longer term, the researchers envisage distributed energy systems that could allow homes, businesses and communities to produce and store their own renewable energy. Small wind or hydropower systems could potentially complement the solar component, helping to provide energy storage when sunlight is unavailable.

Such a system could reduce reliance on fossil fuels and, if deployed at scale, ease pressure on existing energy networks by reducing the need to transport energy over long distances with expensive infrastructure. It could also give communities greater resilience on energy availability, production, storage and use.

For now, however, this remains a future possibility rather than a demonstrated application.

From lab to communities

The immediate challenge is to take the technology beyond its current laboratory proof of concept and test it under more realistic, real-world conditions.

The researchers' next objective is to move towards TRL 5, demonstrating the technology in a more relevant environment. This will mean scaling up the system to larger areas, while ensuring that it can be manufactured efficiently and eventually brought to market.

"We have managed to achieve this at a lightweight systems level. And I can't overstate how important that is," said Ó Manacháin.

There is still a long way to go from a laboratory proof of concept to a commercially deployed green hydrogen technology. But the researchers have already moved the concept well beyond the technology realisation phase.

Their artificial leaf does not imitate nature perfectly. Instead, it borrows one of nature's oldest tricks – capturing sunlight and turning it into stored chemical energy – and combines that principle with modern semiconductor and manufacturing technologies.

If the approach can be made sufficiently durable, affordable and scalable, it could eventually offer a more direct and potentially lower impact way of producing green hydrogen.

It could help put renewable energy production and storage closer to where people live and work. This could give communities greater control over how their energy is produced, stored and used, while reducing their carbon footprint, reliance on fossil fuels and pressure on existing energy networks.

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- FreeHydroCells (CORDIS)
- FreeHydroCells project website
- EU Hydrogen Strategy
- EU Hydrogen Week