Shining light on artificial photosynthesis

Mimicking plant life could be our way out of the energy crisis. Anna Lewcock talks to Tony Harriman to find out more

This year the Olympics come to the UK, and billions of pounds have gone into building the state of the art facilities that the athletes will compete in over the summer. But what if the Olympic stadium – or premier league football grounds – could double up as power stations, providing us with clean fuel?

The idea isn’t so far-fetched. Stadiums can be covered with solar panels to soak up energy from the sun. The problem is that the energy has to be used straight away. What would be really useful would be to find a way to store that energy, so it could be used when the sun goes down.

The seed of an idea
The idea of harnessing energy from the sun isn’t new; it’s been around for billions of years in the process that plants use to get their energy – photosynthesis. The green plant life you see around you has a perfectly developed system for absorbing sunlight and using it to convert water and carbon dioxide into oxygen and carbohydrates. The energy from the sun is ‘stored’ in the chemical bonds of the carbohydrates, ready for the plant to use later.

Scientists have been trying to crack the secret of this complex biological system for decades: ‘It’s absolutely amazing, the level of sophistication that has gone into the evolutionary process,’ says Anthony Harriman of the Molecular Photonics Laboratory at Newcastle University. And now it’s become more important than ever to try and figure out a way to try and imitate what nature has perfected.
We’re fast approaching a fuel crisis. We’ve been happily using fossils fuels like coal and oil to generate power on a huge scale since the industrial revolution, but there’s only a limited supply of these non-renewable fuels on the planet and one day we’ll have squeezed the last drop from the tank.

On top of that is the impact on the environment – burning all that fuel has pumped so much carbon dioxide and other greenhouse gases into the atmosphere that we’ve caused the planet’s temperature to rise, causing dangerous climate change. Both these things mean we urgently need to find alternative, renewable sources of power.

The only option we have is to look to the sky – the sun. ‘There is no alternative,’ says Harriman. ‘No other system known to mankind can generate the energy that we are anticipated to need over the next 20 or 30 years.’ When put that frankly, it becomes less important to be able to duplicate the exact mechanisms within a plant – ‘anything will do that will collect the sunlight and generate a useful chemical fuel.’

Capture the energy

Only a fraction of the sun’s energy reaches us, but what little that does is more than enough: more energy from the sun hits the Earth in one hour than is used by everyone in the world in one year. That’s more than we could ever hope to produce using technology alone.

You’ve probably already seen solar panels – perhaps you have them installed on your house. These show success in tackling one part of the puzzle, as they convert the energy from the sun – photons – directly into electricity. The panels are composed of many individual solar cells made of material that absorbs photons and releases electrons to carry an electric charge. ‘Electricity is fine, but all we can do at the moment is use the sun to charge up a solar panel to feed electricity into the grid, or perhaps charge a battery,’ says Harriman. Where chemistry will really come into its own is in cracking the bigger problem of how we can actually store the energy from the sunlight to use later – artificial photosynthesis.

Divide and conquer

Historically, much of the work in the artificial photosynthesis field has focused on trying to split water into its constituent parts: hydrogen and oxygen. The oxygen can be released into the atmosphere (as it is during natural photosynthesis), and the hydrogen could be put to practical use. If we can find a way to handle the hydrogen effectively, it has huge potential – we could store it in fuel cells that generate electricity without harmful byproducts, combine it with other materials to make more useful products, or perhaps find a way to make it react with nitrogen under modest conditions to create cheap fertilisers for the third world.

Water molecules can be split by electrolysis, with hydrogen gas being given off at the negatively charged cathode and oxygen given off at the positively charged anode. However, if the electricity used to drive this process has come from fossil fuels, it cancels out the benefit of generating the hydrogen to be used as a clean fuel. Work has been done to combine the technology used in solar panels with electrolysis to overcome this, but the set-up would need to be very efficient, use cheap and easily available materials and last for years to be a practical solution. At the moment, that’s not the case.

Another approach is known as ‘photoelectrochemical’ water splitting, and is used in what scientists have described as ‘artificial leaves’. In this arrangement sunlight hits semiconductors that use the energy to directly split water molecules. But finding materials that can work well when in contact with water, as well as being efficient, stable, cheap and durable is still an unfulfilled goal.

A challenge to store electrons

The real challenge for chemists says Harriman, is designing systems that will store electrons – not electricity – for enough time to be able to carry out useful chemical processes. When you’re dealing with photochemistry (ie using light), one photon impact frees up one electron. ‘If you want to generate oxygen from water you need to accumulate four electrons before it’ll work – so you need four photons to get four electrons,’ explains Harriman. But more than that, you need all the electrons at the same place at the same time – ‘and that’s very difficult because they’re highly reactive and tough to control.’ When chemists started working on this several decades ago, they were happy if they managed to hang on to an electron for a nanosecond – one billionth of a second. ‘It was a massive challenge,’ says Harriman. ‘Now we can do it for one second. But I think probably we need 30 seconds before we can do the kind of job that we’re looking for.’

New materials that can cling on to those electrons for long enough are an active area of research, as are new catalysts that will help make the process more efficient. In nature, enzymes act as catalysts and can produce hydrogen from water very effectively. If we can develop...
Most leaves are green due to chlorophyll, an important molecule in photosynthesis. In this experiment, you can separate the different pigments present in a leaf using paper chromatography. Try it yourself.

Artificial leaf (silicon solar cell coated with catalyst) splits the water into H₂ and O₂ as light shines on it.

Find out more
New challenges for photocatalysts
www.rsc.org/ElCo110p14
The artificial leaf
www.rsc.org/CW0509p42

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