‘We want to increase plant yields by a factor of two to four’

RESEARCH ON PHOTOSYNTHESIS WILL BEAR FRUIT

Simulating plants

Plants are champions at putting sunlight to good use. It lets them convert water and carbon dioxide into sugars and oxygen. Wageningen researchers are able to simulate and improve this process. They want to use that to produce biofuels and crops that grow better.

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Your cheese sandwich, your milk, tea, the sheets on your bed, the plastic bag you take to the supermarket, all of these products exist ultimately thanks to plants, and photosynthesis in particular, the process that lets plants convert water and carbon dioxide into sugar and oxygen with the help of sunlight. Biophysicists have been studying this process for years. Now the knowledge they have built up is being used to improve plants, and to simulate the process in order to produce biofuels.

'Look, we have here an artificial leaf that we use to simulate the process of photosynthesis,' says René Klein Lankhorst in his room at Wageningen Plant Research. He shows a photo of a prototype, built by Leiden University. We see a black solar cell in an aluminium frame measuring about 20 by 20 centimetres. This 'leaf', which contains two catalysts as well as the solar cell, is able to use sunlight to split water into oxygen and hydrogen gas. Roughly like a proper leaf does in photosynthesis. Klein Lankhorst: 'We want to convert the hydrogen gas plus carbon dioxide into a liquid fuel such as methanol or formic acid.'

Creating clean fuels from sunlight and water — it seems too good to be true. Yet this first artificial leaf, however primitive it may be, proves that this is possible. Hydrogen gas can serve as a clean source of energy, for example to run cars on. This is one of the results of BioSolar Cells, where Klein Lankhorst was the managing director. This programme, with funding to the tune of 42 million euros, had ten science institutes and about 40 companies working for five years on ideas for putting the photosynthesis process to good use.

DIFFICULT TO STORE

Of course solar energy as a source is nothing new. We produce electricity from solar panels and install solar thermal collectors for hot water. The unique thing about the artificial leaves is that they use sunlight as a source of energy to produce hydrogen gas. 'But gases are difficult to store,' explains Klein Lankhorst, 'so here in Wageningen we looked at how to convert hydrogen and carbon dioxide into a liquid biofuel such as methanol or formic acid.' Biofuels like that can be used to run cars. Or industrial companies can use the liquid fuel as the basis for plastics or other synthetic materials.

The researchers are now seeking additional funding for follow-up research on the conversion of hydrogen and carbon dioxide to liquid fuels.

The Bioscience department at Wageningen Plant Research has found two enzymes that can bring about the conversion of hydrogen and carbon dioxide into methanol in the laboratory. The Wageningen scientists have >

‘Perhaps we need the pigments from the red Ferrari paint’

now joined forces with an industrial partner to link that laboratory setup to the first artificial leaf. Klein Lankhorst: ‘In doing so, we have run into new problems. For example, how to separate out the methanol from the rest of the mixture.’

The BioSolar Cells partners think that in about 30 years’ time, thousands of hectares in the Netherlands will be covered with artificial leaves, that may or may not be connected up to systems for conversion to a liquid biofuel. But artificial leaves will need to become much more efficient first. The current prototype converts about 1 to 2 percent of the solar energy into energy in the form of hydrogen gas, whereas the theoretical maximum is 40 to 50 percent.

REPLACING SILICON

Pigments are crucial to improving the efficiency. The prototype for the artificial leaf contains a conventional solar cell made of silicon that converts solar energy into a charge. But solar cells are not particularly efficient and will eventually have to be replaced by pigments, which can be more efficient. In plants, pigments capture the solar energy and pass the energy along to each other until it reaches a reaction centre. The energy is then converted into a positive charge and a negative charge, which are used to split water into oxygen and hydrogen gas.

But it is no simple matter to replace silicon with pigments as most pigments are sensitive to overexposure to light; they are easily destroyed. In plants, they only last for 20 minutes. That is not a problem as the pigments are soon replaced by new ones. But an artificial leaf should preferably have a useful life of five to ten years. ‘Perhaps we need pigments that are based on the red paint of a Ferrari,’ suggests Klein Lankhorst. ‘They are among the most stable colours we know.’ The technical universities of Delft and Twente are currently trying out those Ferrari molecules.

PREVENTING COMBUSTION

In addition to the solar cell, the artificial leaf also has two types of catalysts: one is needed to split the water into oxygen and positively charged hydrogen ions while the other is for converting the hydrogen ions into hydrogen gas. Those catalyst molecules are placed in such a way that hydrogen gas and oxygen gas do not end up in the same compartment, which would produce a dangerously explosive mixture. Researchers are therefore looking at how the catalysts and pigments are arranged in plant cells.

The artificial leaf also needs to become even cheaper. The catalysts in the prototype contain precious metals such as platinum and iridium. They will need to use cheaper metals like iron, manganese, calcium and magnesium, as plants do. But these metals are soon affected by acidic environments, or indeed alkaline ones. Nature could offer some solutions here too. The metals in plants are embedded in such a way in the pigments that they are protected against excessively acidic or alkaline conditions.

According to Klein Lankhorst, the artificial leaf currently costs a couple of thousand euros per square metre. ‘The price needs to come down by a factor of 1000 to 10,000, roughly speaking, for commercial applications. That is fairly standard for these kinds of developments. We are currently already tentatively exploring the possibility of 3D-printing, for instance, to reduce costs.’

In a follow-up project that is currently being negotiated, the universities and companies involved in Biosolar Cell want to build a second prototype of the artificial leaf that would cover 100 square metres. The groups involved would then be able to try out their ideas for pigments, catalysts or enzymes on two different scales. In this way the teams are gradually working closer to the ideal of cheap, efficient artificial leaves.

KNOWING THE GENES

The BioSolar Cells programme has delivered other results too. Wageningen geneticists have discovered several dozen places in the genome of the thale cress (Arabidopsis), a well-known experimental plant, that have genes involved in photosynthesis. Ten genes have even been localized precisely. ‘If we know the genes, plant breeders can select deliberately for more efficient photosynthesis,’ explains Wageningen geneticist Mark Aarts from Wageningen Plant Research. ‘Seed companies can then cultivate plants that quickly restart photosynthesis after a cold snap, for example.’

Aarts used the ‘Phenovator’ for his research, an instrument he developed with his colleague, horticultural expert Jeremy Harbinson. This image analysis robot has made it possible for the first time to find out what genes are involved in photosynthesis efficiency.

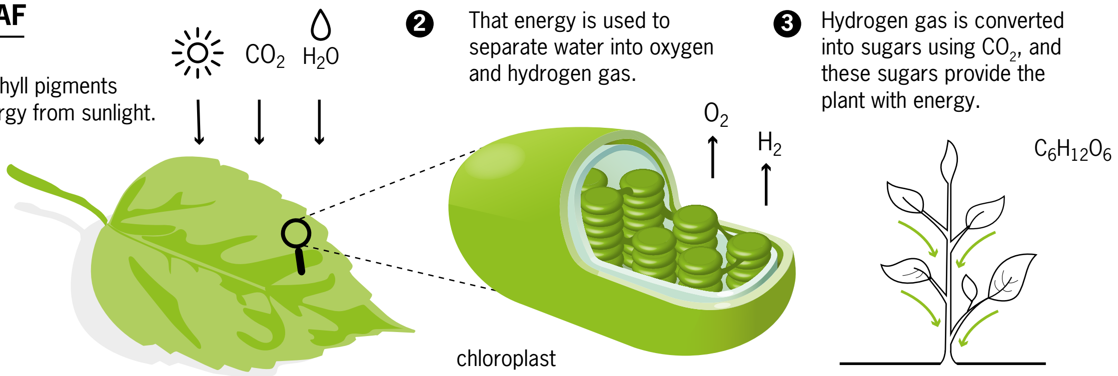
Aarts demonstrates the Phenovator through a hatch in a climate room with Arabidopsis plants. A camera moves rapidly from plant to plant, stopping each time for

REAL LEAF

❶ Chlorophyll pigments get energy from sunlight.

❷ That energy is used to separate water into oxygen and hydrogen gas.

❸ Hydrogen gas is converted into sugars using CO_2, and these sugars provide the plant with energy.

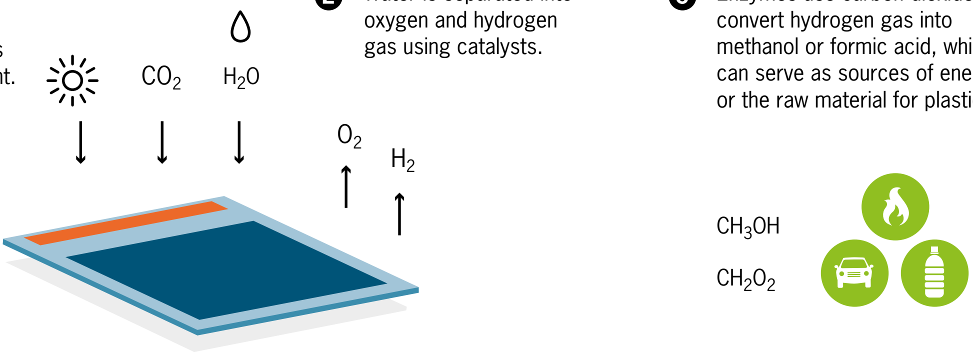


ARTIFICIAL LEAF

❶ A solar cell extracts energy from sunlight.

❷ Water is separated into oxygen and hydrogen gas using catalysts.

❸ Enzymes use carbon dioxide to convert hydrogen gas into methanol or formic acid, which can serve as sources of energy or the raw material for plastics.



15 seconds during which it emits a series of quick pulses of ultrared light. Then the fluorescence is measured. This is the light reflected by plants that has a slightly different, somewhat redder, wavelength to the light that fell on them. The more efficient the photosynthesis, the less fluorescence.
The researchers found the photosynthesis genes by letting the plants grow with a certain stress factor, for example a sudden increase in light or reduction in nitrogen. Some plants deteriorate more rapidly then or take longer to recover, which can all be measured by the Phenovator. By comparing the DNA in all the plants against their adaptability, the researchers were able to find the genes that influence photosynthesis efficiency.'
Klein Lankhorst and some colleagues have written a proposal for a European project — with 48 science institutes in 17 countries — aimed at developing plants that photosynthesize more efficiently. This could help boost crop yields considerably. 'At present, the photosynthesis efficiency of crops is about half a percent,' says René Klein Lankhorst. 'We want to increase that to one to two percent.' ■

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ORDERLY PIGMENTS

Wageningen biophysicists discovered that pigments in nature often operate in a more orderly way than was thought. For instance, the clusters of pigments in photosynthetic bacteria that absorb light turn out to do so in the same, orderly fashion. The pigments all exhibit a gradual change in colour towards the centre of the clusters, where the charge is finally released for splitting the water molecules. 'So you can chuck in a pile of pigments in an artificial leaf, but it might work better to arrange them in a specific order,' says Herbert Van Amerongen, professor of Biophysics at Wageningen.
It also turns out that clusters on the underside of leaves have half as many pigment molecules again as clusters on the upper side, where the light falls. So plants compensate for the lack of light with increased reception capacity.
'We are studying how the light is distributed among the pigments,' explains Van Amerongen. He and his group developed measurement techniques that can be used to determine the efficiency of real and artificial leaves. The leaf is bombarded with pulses of light lasting just a few femtoseconds (10-15 s). Then the researchers measure the fluorescence that is emitted and how that changes. That shows them, for example, how efficient the energy transfer is between pigments if there is too much light on the leaf, or indeed too little.