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Chemistry & Industry



# Running on hydrogen

## Rethinking the culinary experience

Scientists and chefs come together to examine options for the future

## Origami: the answer for self-folding molecules

New ways of building very small 3D objects for electronics and biomedicine

## ME: not necessarily all in the mind

Evidence for chronic fatigue syndrome as a biological illness

# CAM do biofuels

**Hardy and water-efficient CAM plants could provide clues to sustainable sources of biomass feedstock that don't compete with food production, Nina Morgan reports**

According to a 2013 report released by the International Energy Agency (IEA), biomass now provides around 10% of the world's energy. However, opinions are divided as to whether this percentage could – or should – grow.

It takes roughly 1t of biomass to produce a barrel of liquid fuel, and the main energy crops currently used for bioethanol production – corn (maize), switchgrass and sugarcane etc – compete with food crops for land and water resources. As Chris Llewellyn Smith, director of energy research at Oxford University, UK, pointed out in a keynote address at the Oxford Climate Forum in November 2014, growing enough biomass to meet the world's energy needs would require 175% of the land area of the US, equivalent to 30% of all world land used for agriculture.

When transport and harvest costs are taken into account, as well as the CO<sub>2</sub> released by ploughing up more land, the carbon footprint from biofuels is greater than first imagined.

But that's no reason to give up on biofuels altogether, according to Llewellyn Smith. Improving the efficiency of existing technologies, such as anaerobic digestion for biomass to energy conversion (see Box), could be part of the answer, Llewellyn Smith believes. So too could so-called CAM (crassulacean acid metabolism) plants that capture and store CO<sub>2</sub> at night – rather than during the day

as do most other plants.

'CAM plants can grow in hot dry environments where food crops can't. They represent a huge resource,' said Llewellyn Smith. 'By using just 15% of the world's semi-arid or degraded land, we could use CAM plants to produce 0.5 terawatt – if we knew how to turn them into electricity.' Familiar garden examples include succulents such as sedums, ice plants, cactus and agaves.

'CAM is an adaptation that has cropped up many times during the evolution of flowering plants,' explains James Hartwell, senior lecturer in plant metabolism at the University of Liverpool, UK. 'The majority of plants capture CO<sub>2</sub> during the day through tiny pores on the leaves, known as stomata, then convert it into sugar via one of two forms of photosynthesis, referred to as C3 and C4. CAM plants, in contrast, open up their stomata and build up a chemical store of captured CO<sub>2</sub> during the night. They then use this to carry out photosynthesis during the day. This allows them to close their stomata during the day, greatly reducing water loss and enabling them to live in hot dry environments.'

Several species of agave are already grown commercially, Hartwell points out – including *Agave tequilana* (for tequila production) and *Agave sisalana* (for fibre). 'Agaves can succeed where plants like wheat can't because they are very good at taking on lots of liquid when it

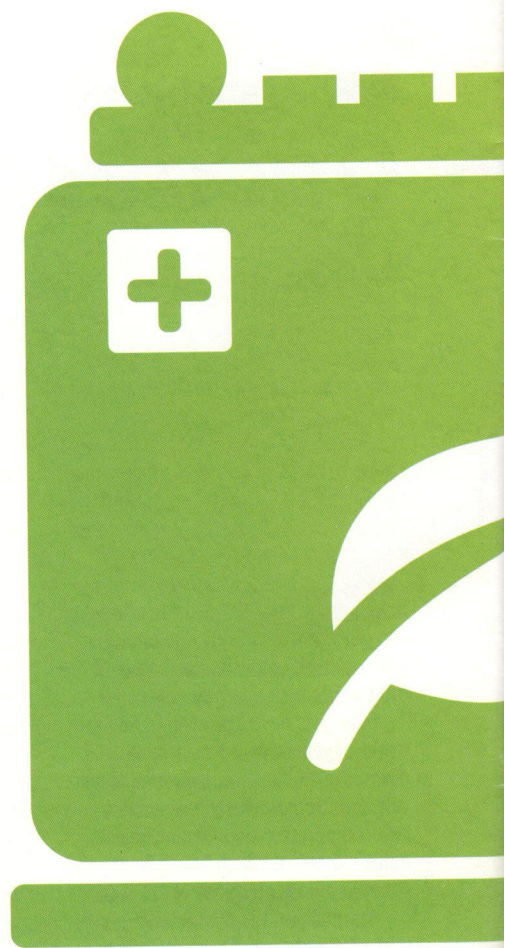
#### Further reading

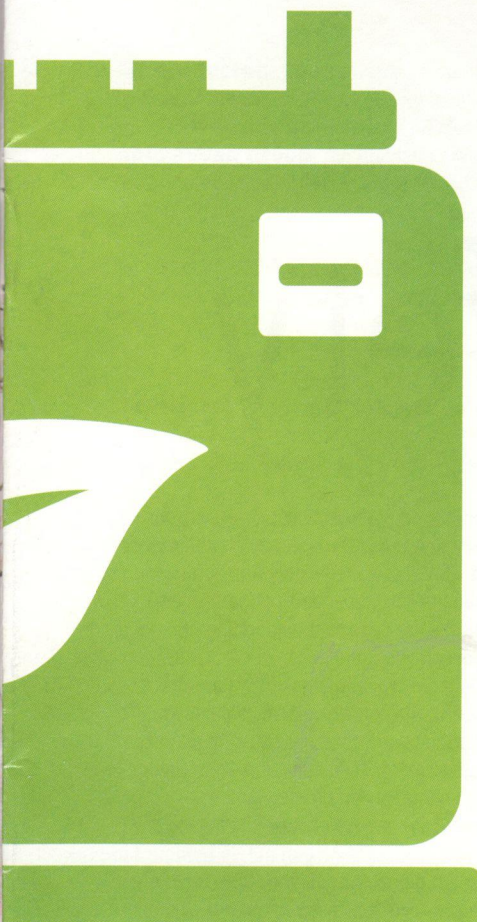
- 1 The biodesigner, *International Innovation*, <http://internationalinnovation.com/the-biodesigner>
- 2 M. J. West-Eberhard et al, *Science*, 2011, **332**, 311.

is available, and then continuing to grow for much of the dry season,' he says.

Now, thanks to their high productivities, high sugar content and their efficient use of water, other CAM species are attracting attention as potential feedstocks for bioethanol production.

In a lifecycle analysis for agave-derived bioethanol, researchers suggest that – in terms of energy and greenhouse gas (GHG) balances, as well as in ethanol output and net GHG offset per unit land area – ethanol derived from agave is likely to be superior, or at least comparable, to ethanol from maize, switchgrass and sugarcane (*Energy & Environmental Science*, X. Yan et al, *Energy Environ. Sci.*, 2011, **4**, 3110). The group's analysis also highlights the





promising opportunities for bioenergy production from agaves in arid or semi-arid regions with minimum pressure on food production.

One company taking this prediction seriously is AusAgave (Australian Agave) in South Australia. The company, which specialises in growing specific agave species for sugars and fibres, also carries out in-field R&D to improve yields of agave varieties adapted for cropping in marginal environments.

In 2014, California-based biotech company Byogy Renewables invested in a strategic partnership with AusAgave, aimed at developing multiple feedstocks as a source of low cost sugars for the production of the bioethanol precursors for renewable fuels and chemicals.

According to AusAgave ceo Don Chambers, growing agave in Queensland has allowed the company to produce substantially more biomass per acre than sugarcane, with twice the sugar content.

Meanwhile, Hartwell and his colleagues are working with teams led by John Cushman of the University of Nevada, Reno, and Xiaohan Yang at the Oak Ridge National Laboratory in Tennessee in the US, and Anne Borland of Newcastle University, UK, to understand the chemical and biological processes that enable CAM photosynthesis to occur in the first place.

'Different species do CAM in slightly different ways,' explains Hartwell. 'Each group is looking at great detail – down to the level of genes and proteins – to try

to understand which genes and proteins are required by various species to achieve their version of CAM. The hope is that by identifying and achieving a greater understanding of every gene and protein that's involved in the CAM process we will be able to open up the possibility of engineering CAM characteristics, especially their high water use efficiency, into non-CAM plants.'

The project's ultimate goal is to introduce CAM-like properties into non-CAM species that show good potential for biomass production. The target species is poplar – a fast growing tree able to grow in a wide range of habitats, and a plant whose genome is already well studied.

The idea is to develop a poplar tree that would use its 'normal' C3 photosynthesis to grow when water was available, and then transition to CAM during times of drought and high temperatures.

The research could lead to poplars that require up to 80% less water for biomass production and will be able to grow in more marginal habitats. Ultimately this type of research could make it possible to adapt other biomass plants to grow in hot, dry areas where nothing else would grow.

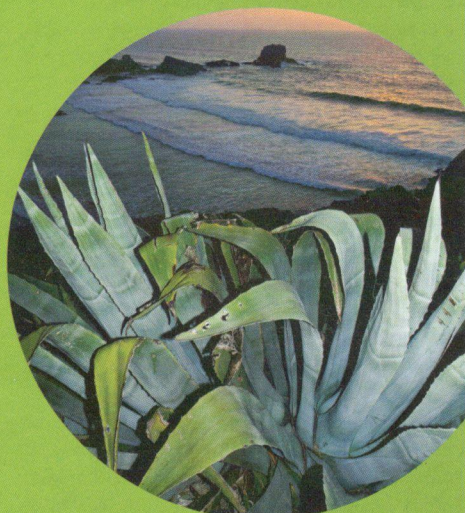
'The technologies we are developing to identify plant genes and insert them into other plants will aid in the development of more drought-tolerant food crops,' says Hartwell. 'Long term, this could help to secure food, feed and fuel stocks for the future.'

## Out of Africa

'CAM plants have great potential as a biomass source for use in anaerobic digesters,' says Mike Mason, chairman of Tropical Power, a company based in Oxford, UK, with subsidiaries in Ghana and Kenya.

In January 2015, Tropical Power began commissioning a 2.4 MW grid-connect anaerobic digester (AD) plant at Gorge Farm on the south shore of Lake Naivasha in Kenya, the first such plant in Africa. The Gorge Farm AD power plant is more than four times the average size of an AD plant in Germany. It will produce methane-rich biogas to power a generator to produce electricity for sale to local farmers and the grid.

The plant currently relies on a feedstock consisting of agricultural waste from crops such as beans, broccoli and baby sweet corn grown on Gorge Farm and destined largely for the UK market. However, it is also investigating the potential of CAM plants. By linking up with plant scientists at Oxford University, UK, it hopes to tackle some of the basic questions about CAM plants, such as how to grow the plants to get high productivity; which plants are suitable for different climatic zones; and how best to harvest them. 'Until we know what is out there in the treasure chest, we can't begin to imagine what the resource base looks like,' says Mason.



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