Fern of the future?

Held in the palm of a human hand, a single specimen of *Azolla filiculoides* looks downright inconsequential. Even with the scaly leaves of this miniature aquatic fern spread flat, it barely spans the distance between the creases that cleave the flesh. Its fibrous root tendrils dangle like a lock of matted hair, adding to its overall impression of impotence and making it even harder to believe that *Azolla* might help address humanity's greatest challenges. That it could is the hope of a team of scientists investigating *Azolla*'s potential as a sustainable source of biofuel and protein. They presented their preliminary results last month at the EGU General Assembly.

More reminiscent of a moss than a fern, *Azolla* has a long history with humans. Rice farmers in ancient China used it for thousands of years as green manure to replenish their paddies, unknowingly harnessing the power of its symbiotic nitrogen-fixing cyanobacteria. *Azolla* then enjoyed a moment of global celebrity in the 1970's and 80's as Western agricultural researchers began to recognise its potential before it fell abruptly into disrepute. Invasive *Azolla* grows like a weed: in 1993, it made headlines in Europe when blooms choked the Guadiana River in Portugal following an influx of phosphate runoff from upstream farms and factories.

But this ignominious debut did not alert the scientific community to *Azolla*'s biofuel potential. In fact, the diminutive fern did not come to the attention of Henk Brinkhuis, a geologist at Utrecht University in the Netherlands, until eleven years later, when copious quantities of *Azolla* spores turned up in ancient sediments from the Arctic Ocean. Scientists collecting cores in the newly ice-free Arctic Ocean in 2004 discovered evidence that, during the balmy Eocene epoch about 50 million years ago, *Azolla* blanketed the pole. They hypothesised that, in collusion with other changing environmental factors, these humble plants might have altered the climate – kick-starting the global cooling that drove Earth into its present icehouse state – by consuming CO_2 and storing it in their biomass, where it has remained at the bottom of the Arctic Ocean.

Now, *Azolla* may be poised to help bring down CO_2 yet again, but in an entirely different way: awed by its irrepressible capacity for reproduction (it can double in mass every two days), Brinkhuis assembled an interdisciplinary group of scientists from Utrecht and Wageningen Universities in the Netherlands and Imperial College in the UK to investigate the suitability of several species of *Azolla* for commercial biofuel production. Peter Bijl, also a geologist at Utrecht, coordinates the project from the helm of the Laboratory of Palynology and Paleobotany (LPP) Foundation, a non-profit that specialises in bridging the gap between academia and industry.

"The *Azolla* lipids are very special in terms of composition and carbon chain length, diversity and functional groups," Bijl says, discussing the new results he presented at the EGU meeting. The long-chained lipids store energy, making them suitable for biofuel, while

Azolla filiculoides close up. (Credit: Robert Vidéki, Doronicum Kft., Bugwood.org)

other types of *Azolla* compounds can be manipulated into specialised high-value chemicals like lubricants. From what remains of the fuzzy green-red ferns after extracting these molecules, Bijl and his colleagues demonstrated that they can concentrate protein of the desirably nondescript variety (think soy) used in processed foods and animal feed. This has tremendous benefits from an economic point of view, Bijl says: "Basically, you can sell the same product twice."

Azolla also stands out as a radical alternative to other biofuel crops like corn, oil palms, and sugar cane that have become the source of global controversy. The problems that plague these other biofuels – once a seemingly promising way forward – include their competition with food crops for arable land, their suitability to tropical regions that often face a trade-off between rainforest and crop land, and the fact that these crops require so much synthetic fertiliser that, in the long run, they are far from carbon neutral.

Azolla, however, might sidestep these issues. First, the fern can be grown on marginal land that lacks agricultural utility. For example, Bijl says: "In India, there are large coastal areas where the groundwater has become brackish, but there are certain species of *Azolla* that can tolerate this." Second, the fern, like its full-sized relatives, thrives in relatively low light conditions like the natural sunlight available at mid-latitudes, alleviating the burden on low-latitude countries to grow most of the world's biofuel or the need for expensive indoor growing facilities. Third, with an endless supply of nitrogen, it requires few inputs, especially if grown in a closed system.

The holy grail of a closed system – nothing added, nothing wasted, endless product – has proved elusive for traditional biofuels. However, *Azolla* cultivation might come close because free sunlight, nitrogen and CO_2 constitute the primary inputs, and the whole process

Azolla growth in Broken Creek near Cobram in Victoria, Australia. (Credit: Arthur Mostead)

takes place in isolated tanks where nutrients can be reclaimed from wastewater streams and fed back into the next batch. Heat speeds up the process, but that could come from unexpected sources. On an industrial scale, Bijl envisions coupling *Azolla* production facilities to industrial operations like concrete factories or steel plants where heat and CO_2 abound.

Other biofuel experts agree that *Azolla* truly does differ from previous crops in important ways. Keith Smith, a geologist at the University of Edinburgh who has studied the greenhouse gas emissions of growing traditional biofuels, says that *Azolla*'s natural nitrogen source would greatly reduce such emissions. Its ability to grow on marginal land helps too, he says, because what really matters is avoiding "land use change whereby forest land becomes converted to agricultural land. The CO_2 emissions associated with this process are huge compared with any environmental benefits from using biofuels instead of fossil fuels."

However, Tad Patzek, Professor of Petroleum and Geosystems Engineering at the University of Texas at Austin and a prominent biofuel critic, thinks *Azolla* is just another doomed biofuel darling. "It makes no difference what less or more exotic source of biofuels we find," he wrote in an email. "They all – without an exception – are unsustainable and/or harmful at the scales we want to deploy them." A truly closed system can't exist, he argues, because removing biomass and the micronutrients it contains violates "the thermodynamic definition of sustainability". In addition, there are other conceivable concerns regarding the threat posed by invasive *Azolla* if spores escape into the wild and cautionary tales of other non-food biofuel crops like switchgrass and jatropha that failed to fulfill perhaps overly-inflated hopes.

Bijl and the LPP Foundation harbor no delusions that *Azolla* will save the world. However, their research reveals that the fern could produce commercially viable quantities of chemicals and proteins without the human and environmental costs of other biofuels. With the results of the preliminary investigations now in hand, the LPP Foundation hopes to attract business partners like energy giants, specialty chemical companies, and food and animal feed manufacturers.

So far, Bijl says there have been hints of interest from potential collaborators, but nothing concrete. Will anyone bite? It's too soon to tell, but in the meantime, Bijl's vats of *Azolla* will just keep growing and growing, synthesising lipids and proteins without any regard for mankind, just as they have done for 50 million years.

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Flash, bang, jet: new observations of volcanic plumes

It erupts every day. Thousands of explosions occur every year. And, if you look closely, you might just catch sight of the lightning.

The Japanese volcano Sakurajima nestles in Kagoshima bay, spewing its jets of volcanic debris onto the 680,000 residents of the nearby city. Corrado Cimarelli, a volcanologist at the Ludwig Maximilian University in Munich, comes here to observe the lightning. He uses high-speed cameras to capture the moment and then recreates the spectacle in his lab.

"My colleague Miguel Alatorre-Ibargüengoitia was doing experiments looking at [volcanic] jets and we discovered the lightning in one of these experiments, completely by chance," says Cimarelli. "Miguel and I were looking at the videos and we thought: what was that white thing in the video? So we went back and we saw that there were actually many of these flashes."

To recreate volcanic lightning in his lab, Cimarelli uses about 100 grams of ash per experiment, but each one lasts for only a few milliseconds. "Without the high-speed camera you don't see anything, you just hear a big boom and everything is finished," he explains. The lightning is caused by the separation of charged particles within the plume: the ash carries electrical charges, the ash expands, and the electrical charges become separated. The flash of lightning occurs when the charge difference is so great that it can overcome the resistive air in between. Over time the lightning flashes get bigger but less frequent. "This is something we can actually observe in volcanic plumes," says Cimarelli, "you start with an acceleration of particles and you see a lot of crackling of lightning around the vent. Then, with time, you build up longer and more powerful lightning." Cimarelli and his team also found a relationship between the size of the particles and the number of flashes produced: more flashes are seen when there is a greater proportion of smaller particles.