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.

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Volcanic lightning has been proposed as the 'spark of life', electrical discharges that aided the first formation of organic molecules. Cimarelli is excited by the possibility: "Volcanoes not only produce the spark but they actually contributed to the formation of the early atmosphere on the Earth. All the gases are actually escaping from the volcanoes. I'm not saying life was produced by volcanoes, but it's a sexy idea. We don't need to look for strange explanations if everything is there." Cimarelli hopes to pursue this idea in future experiments.

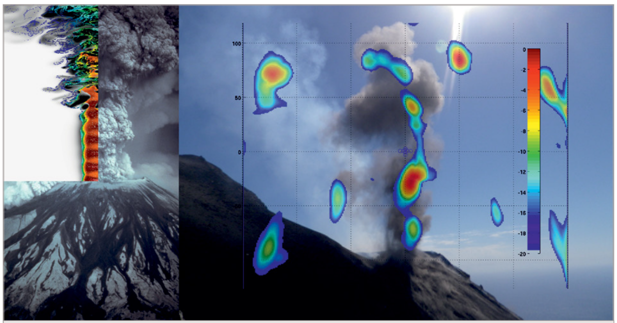
There's also a very practical application in the form of hazard management. "We cannot predict the eruption, but we can tell something about the structure of the plume and the fate of the ash from the plume. But we need to couple this technique with other monitoring," says Cimarelli. This is where the sounds come in. "During monitoring at night our camera can't see the very beginning of the eruption, but we can spot it because of the sound. So we can synchronise our camera with the microphone and then use the microphone signal to look in the video to find the beginning of the eruption." These techniques are being used in collaboration with researchers at the Universities of Kyoto and Kyushu in Japan.

Left: Volcanic lightning at Sakurajima volcano in Japan. Right: Volcanic lightning recorded by a high-speed camera in the lab. Images courtesy of Corrado Cimarelli.

Jörn Sesterhenn, from the Technical University of Berlin, is also very interested in the sounds produced by volcanic jets. When a volcano erupts the key parameters to determine are the diameter of the vent, the speed of the jet and the volume of ash in the flow. These variables can be very hard to measure directly, but, explains Sesterhenn, we can listen instead.

"We go to the volcano and take pictures and also place microphones. At home we compute the whole thing using a supercomputer. From this computation we find out how the acoustic waves radiate. From these characteristics we do what we call beam forming and identify the sources of the sound [in space]." In other words, Sesterhenn and his colleagues can make a map of where in the jet the noises are coming from.

Many volcanic jets are supersonic. "Every jet which has a pressure inside the volcano that is twice the ambient pressure will be supersonic," explains Sesterhenn. These supersonic jets have certain characteristics, which Sesterhenn has reproduced in his numerical models. When the jet first starts it produces a vortex ring. "It's a bit like a smoke ring," says Sesterhenn, "if you have a fluid coming out of a tube you have friction between the fluid and the wall and this causes the fluid to start turning." Then there are shock cells, patches in the jet that correspond to supersonic booms. Some jets are like



Left: The eruption column at Mount St. Helens and a numerical model of a volcanic jet. Shock cells are visible as dark red patches within the jet. Right: The location of acoustic sources within a volcanic jet. Images courtesy of the US Geological Survey and Jörn Sesterhenn.

single puffs of smoke – just one vortex ring is produced; others are more continuous and include lines of shock cells.

Sesterhenn is also able to learn about the ash content of the jet purely from acoustic observations. "If you have ash, the ash changes the structure of the jet. For example, with no ash you have a certain mode of behaviour for a certain Mach number (the ratio of the speed of the jet to the speed of sound) – for example a spiral motion. If you keep everything the same but alter the ash content then this motion changes. If we knew everything else about the jet we could infer the ash content from the type of motion – whether it's spiraling or flapping, for example. If we know other things, like the vent diameter, we can calculate the volume fraction of ash in the air."

"Ultimately this will be helpful for hazard management," he explains. "Microphones are very cheap devices – they cost a couple of hundred Euros – but it's not a short term goal."

Flashes and bangs in volcanic jets make for exciting research topics, but they also reveal vital information about volcanic eruptions as they progress. Hopefully, real-time observations of these sights and sounds will soon feed into disaster management initiatives.

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Notes

A video of Cimarelli's volcanic lightning in the lab is available online.
Sesterhenn's work has been accepted for publication in Geophysical Research Letters.

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