MARTIN O'NEILL

How to grow metal

Mining is a dirty, damaging business. Can we get the metals we need from farms instead? **Michael Allen** investigates

WHEN you cut into a branch of *Phyllanthus rufuschaneyi*, the sap runs an intensely bright blue-green. That's the sort of thing that makes plant hunter Anthony van der Ent sit up and take notice. So when he came across this unusual woody shrub at a national park ranger's station in Malaysian Borneo, he knew he had to investigate further. It turned out that the sap was chock-full of nickel.

Van der Ent, based at the University of Queensland, Australia, is one of several scientists who think plants like this might be a solution to one of the most pressing problems of our age. Demand for many metals has been creeping upwards for years because they are essential ingredients in everyday tech like phones and computers. Our appetite for these metals will soon become even more voracious because they are also needed for green technologies such as wind turbines and the rechargeable batteries in electric cars. Yet mining them is difficult, environmentally damaging and sometimes extremely dangerous.

Could those problems be addressed by growing metals instead? That is what van der Ent believes. We will soon see if he is right as the first metal farms are now springing up in China, Europe and Malaysia. On the face of it, these farms are all-round winners: the profits are tidy, the environmental credentials excellent. So steel yourself for the latest disruptive mining technology: the plant.

The nickel colouring the blue-green sap of the shrub van der Ent discovered is just one of the metals we depend on. Nickel has long been a crucial ingredient in stainless steel. It is also used in many lithium-ion batteries in electric vehicles, phones and other consumer electronics.

Demand is expected to surge over the next decade as electric vehicles become more widespread. A leading resource consultancy has forecast that the amount of nickel needed for use in electric vehicles in 2025 will be 256,000 tonnes, roughly double the demand in 2019. Other crucial technologies, from wind turbines to magnets to lasers, also require a witches' brew of metallic elements.

Like many metals, nickel is usually obtained by strip-mining. Vegetation is removed from the ground and explosives are used to reveal the mineral seams beneath. It is a destructive practice. The French territory of New Caledonia in the Pacific holds some of Earth's largest nickel deposits and it has been ravaged by mining. With fewer trees to slow water flowing off the land, streams of pollution from mines run into the sea, killing fish and coral. The ore is often shipped for smelting, a process that produces toxic fumes and mountains of waste.

"One relative of cabbage contains 2000 times as much nickel as a typical plant"

It is no surprise that plants contain some metal. Their roots take in minerals from the soil that provide elements like iron, zinc and more. What is surprising is that some plants contain truly massive quantities of metal.

This first came to light in 1948, when botanist Ornella Vergnano discovered a plant called *Alyssum bertolonii* in Tuscany, Italy. This relative of kale and cabbages contained 10 milligrams of nickel in every gram of its dried tissue. That's an astonishing 2000 times as much as a typical plant.

Hundreds more of these so-called hyperaccumulator plants have since been discovered. No one knows why they do it. Our best guess is that it serves as a defence against pests, because the high concentrations of metal make the plant tissue toxic.

These plants don't grow just anywhere because it takes a special type of soil to supply such huge amounts of metal. Back in our planet's early years, when its surface was still molten, metals tended to sink. They ended up in what is now the mantle, just below the crust. This means the mantle is made of softened ultramafic rock, which is high in iron, magnesium and other metals. In areas that had lots of tectonic activity long ago, this ultramafic rock was pushed to the surface, resulting in soil that today is rich with metals. It is in these areas that hyperaccumulators are found.

For decades, these plants were regarded as mere curiosities. Then in 1997, Rufus Chaney, an agronomist at the US Department of Agriculture, and his colleagues demonstrated that they could harvest the plants and extract a nickel-rich "bio-ore". The idea of metal farming was born – but it would be a while before it got serious attention.

One incident that helped draw that attention was van der Ent's discovery in Borneo. The plant's sap turned out to contain a whopping 25 per cent nickel by weight. "It is the best candidate metal crop we have ever found," he says.

The first thing he did on seeing this plant was ask the park ranger where it came from. He couldn't remember. So van der Ent offered local people a reward if they could tell him – to no avail. It wasn't until 2015, a few years after the initial discovery, that he chanced upon a clump of the plants growing on a nearby hillside. From there, he began experimenting with farming metal, otherwise known as agromining or phytomining, as an environmentally friendly alternative to mining. He even named his shrub *Phyllanthus rufuschaneyi* in homage to the inventor of agromining.

If you go to the state of Sabah in Borneo these days, you can find what van der Ent calls the "first tropical metal farm". There, he and his colleagues are growing that nickel-loving woody shrub. Each year, they coppice the plants, pulp them and extract the metal. In 2019, they reported a yield of 250 kilograms of nickel a year – currently worth almost $4000 – from each hectare of land.

Guillaume Echevarria at the University of Lorraine in France is a long-time collaborator of van der Ent's, and wanted to start his own metal farms in Europe. *Phyllanthus rufuschaneyi* wasn't the obvious choice, being at home in tropical conditions. So Echevarria and his team set up a series of agromining plots, mostly on ultramafic land in Albania, that grow a different hyperaccumulator that resembles kale. Local farmers use tractors to sow and harvest the crop. It is then baled and transported to Echevarria in France. There, the plants are burned to yield nickel-rich ash from which the metal is extracted using a chemical process.

Although these European farms can't quite match the yields of those in Borneo, the team still gets up to 200 kilograms of the metal per hectare of crop. That amount of nickel is worth around $3000 at today's prices, which makes it look like a sustainable business. For comparison, British farmers can sell a hectare's worth of wheat for about $2100.

Metal farming can also claim good marks when it comes to carbon emissions. Plants suck in carbon dioxide as they grow. Burning them releases it and so do the tractors, trucks and machinery used to plant, harvest and transport the crops. However, in Echevarria's project, the burning of the plants doubles as a heat source for nearby buildings and so the whole process ends up being carbon neutral, according to a life-cycle analysis he did.

These farms are small though. Could they provide a scalable alternative to mining? "There are very large areas around the world where phytomining could take place," says van der Ent. The island of Sulawesi in Indonesia alone has over 15,000 square kilometres of ultramafic soils, he points out.

Healing the land

Echevarria is more cautious. He says that much of Earth's ultramafic land sits within protected areas and biodiversity hotspots. If an agromining rush led to monocultures of hyperaccumulators replacing natural vegetation, that could be a biodiversity disaster. However, he still thinks agromining could meet a few per cent of global nickel requirements. That's not to be sniffed at, given how demand for the metal is expected to skyrocket. "My understanding of the market for metals is that any source will be important," says Echevarria.

Planting hyperaccumulators could even heal some of the damage wrought by strip-mining in places like New Caledonia. The plants won't significantly reduce the natural nickel content of soils, but they could help revegetate and stabilise them.

71%

The portion of the world's mined cobalt that came from the Democratic Republic of the Congo in 2019

Source: US Geological Survey

$240,000

The cost of a tonne of dysprosium, a rare earth metal required in many technologies

Source: US Geological Survey

256,000

The amount of nickel, in tonnes, forecast to be required in electric car batteries in 2025

Source: Wood Mackenzie

The shrub *Phyllanthus balgooyi* oozes a brightly coloured sap that is full of nickel

ANTONY VAN DER ENT

Farming vaccines

Hopes of an end to the covid-19 pandemic are pinned on developing vaccines and producing them in massive quantities. Plants could help.

Those vaccines that are based on proteins are usually cultured in animal cells. Flu vaccines are cultured in chicken eggs, for instance. This requires special lab equipment. But we have long toyed with the idea of producing proteins using plants instead, an idea called molecular farming.

It works by giving plants the biological instructions for making a particular viral protein, so that their cells become factories pumping it out. Then you harvest the leaves or other tissues and extract the goodies. This technology is less developed than using animal cells, but far easier and cheaper. "All you need is greenhouses", says Helga Schinkel at the Fraunhofer Institute for Molecular Biology and Applied Ecology in Germany.

Canadian company Medicago has already produced a candidate covid-19 vaccine through this method. It uses plants to make virus-like particles that mimic the coronavirus's outer structure, complete with the spike protein it uses to enter human cells. Such proteins can provoke our immune system to make antibodies to the virus and protect us.

Molecular farming may still be too immature to have a big impact on the current pandemic. But in future, it should be a great way to produce vaccines, says Schinkel, especially in low-income nations. "This is the perfect way for developing countries to make their own medications because they don't need all this expensive equipment," she says.

DEAGOSTINI/GETTY IMAGES

Mining has stripped vegetation from the French territory of New Caledonia, a group of Pacific islands

Agromining could also give farmers in ultramafic areas a financial boost, says Ángeles Prieto Fernández, a soil scientist at the Spanish National Research Council. "These soils really are quite poor for other agricultural applications," she says. "It is a way to use them and get an extra income." Echevarria agrees, saying that many farms on such land in Greece, Albania and Bulgaria are being abandoned.

Agromining isn't the only way we can grow our way out of trouble. Plants and microorganisms are sometimes used to soak up pollutants like heavy metals or chemicals from the soil after natural disasters. There is even talk of using plants in the fight against covid-19 (see "Farming vaccines", left).

Meanwhile, metal farmers are looking beyond nickel. Plants that accumulate arsenic, cobalt, manganese, zinc and rare earth elements have been discovered. Farming rare earth elements would be especially interesting, says Fernández. These are critical for many modern technologies and demand is increasing. "We really need these and it is expensive and difficult to get them," she says. "Even in mines they are in very low concentrations."

A team led by Marie-Odile Simonnot, also at the University of Lorraine, has been assessing a fern called *Dicranopteris dichotoma* that grows naturally on waste heaps near rare earth mines in China's Jiangxi province. Field surveys suggest it is possible to harvest about 300 kilograms of mixed rare earth elements per hectare of this crop, with lanthanum, cerium, praseodymium and neodymium chief among them. This could be a lucrative operation: the ore praseodymium oxide fetches around $49,000 per tonne. The team is now optimising the techniques for extracting these elements and working with scientists in China to run field trials at old mining sites.

For his part, van der Ent is out there doing what he does best: plant hunting. He and Echevarria reckon there are many more hyperaccumulators waiting to be discovered – and they have a better way of finding them than hoping for chance encounters in Borneo.

These days, they spend a good chunk of their time pacing the world's herbariums with a handheld instrument called an X-ray fluorescence spectroscope. Point one of these at a sample of pressed plant tissue in a catalogue and it will give you an instant read-out of the elements it contains. They have discovered hundreds of new hyperaccumulators this way. If they can be cultivated, then all of them will have sap running with metals. ▮

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