Feature

A New York experiment is part of a commercial race to develop ocean-based technologies to extract carbon dioxide from the atmosphere.

By Jeff Tollefson

CAN ADDING ANTACIDS TO THE OCEAN SLOW GLOBAL WARMING?

Bonnie Chang squints at a tube of sediment collected beneath the shallow waters off North Sea Beach – about a two-hour drive from New York City. She's looking for green mineral crystals that her team added to the sand last year. If all goes as planned, these olivine crystals will cause the ocean to absorb more carbon dioxide from the atmosphere – a climate solution that could potentially be scaled up around the globe.

This is one of the first field trials of a concept known as ocean alkalinity enhancement – essentially using antacids to help the ocean digest CO_2. The two-year experiment is run by Vesta, a start-up climate company based in San Francisco, California, with enthusiastic support from local community leaders. Just metres down the beach, a newly installed welcome plaque proclaims that visitors are about to step onto "the world's first carbon-removing beach".

Chang, a chemical oceanographer leading the field work for Vesta, isn't so sure just yet. Looking at the clear sediment tube, she is disappointed to discover a distinct layer of olivine crystals buried beneath about 10 centimetres of beach sand.

"The olivine is deeper than I was expecting," she says. "I was hoping it would stay on top and mix in."

That might signal trouble because it could slow down a series of reactions that could – along with many other factors – determine whether the beach lives up to its promise.

Vesta is one of many companies investigating unusual solutions for removing carbon from the atmosphere. Global temperatures are quickly approaching 1.5 °C above preindustrial levels and nations have yet to rein in emissions. Models suggest that the world would need to pull billions of tonnes of CO_2 from the air each year by mid-century to keep temperatures from rising beyond 1.5–2 °C – a goal countries agreed on with the 2015 Paris climate agreement. Scientists, entrepreneurs and investors are increasingly looking to the oceans for solutions, which cover 70% of the planet and already soak up more than one-quarter of the greenhouse gases emitted each year.

In this area, ocean alkalinization has garnered increasing interest, with scientists focusing on ideas ranging from mineral supplements to the direct removal of CO_2 from seawater using electrochemistry. This is partly because of ocean alkalinization's nearly limitless potential, but also owing to the fact that it relies on fairly predictable chemistry and physics rather than more complex biological solutions, such as fertilizing phytoplankton in the ocean or industrial-scale seaweed farming. Indeed, if properly applied, ocean alkalinization technologies wouldn't change life in the ocean much at all, say proponents.

"It's almost too good to be true," says Katja Fennel, an oceanographer at Dalhousie University in Halifax, Canada, who is preparing for a field trial involving a different technology in Nova Scotia later this year. "But doing this at a scale that is relevant for carbon removal – that's a daunting challenge."

Green beaches

Vesta kicked off its project on North Sea Beach last July and worked with the local community on a previously planned project to add sand to the beach. The company applied nearly 400 cubic metres of olivine – making

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A team takes a core sample of ocean bottom sediments at North Sea Beach, New York.

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A field crew from the climate company Vesta collects water samples at the beach for later analysis.

up around 5% of the newly added sand — to roughly 400 metres of the coast, leaving waves, tides and storms to spread it around. A field team spent the next several months extracting sediment cores and taking water samples to track where the olivine crystals went and how quickly they dissolve. Researchers also began looking for any potential impacts on plants and animals, including those from heavy metals such as nickel and chromium that are common in such mineral deposits.

The strategy behind ocean alkalinity enhancement is to speed up a natural geochemical weathering process that helps to stop the planet from overheating over long time scales. These chemical reactions ultimately transfer CO_2 from the atmosphere into the deep ocean and eventually into Earth's crust. Accelerating that process, in theory, will pull more CO_2 from the atmosphere and help to limit global warming.

Initial results from sampling conducted last year suggest everything is working as planned so far in the pilot project, says Grace Andrews, Vesta's head of science. Early monitoring using closed chambers placed on the sea floor indicated that the olivine is making the seawater more alkaline, while ecosystem studies have yet to identify any heavy metals building up in invertebrates such as worms and molluscs.

Vesta calculates that the North Sea Beach project will remove roughly 400 tonnes of CO_2 from the atmosphere, after factoring in emissions from mining, grinding and shipping the olivine from Norway. The company plans to sell carbon credits, but the US$2-million pilot project will neither make money nor alter the climate, says Andrews. "It is a proof of concept."

Storms reshuffled everything during the winter, so one of Chang's first tasks when this year's fieldwork began last month was to find the olivine. Initial inspections suggested that it had spread farther than expected, and in some places the mineral got buried, which Chang says is less than ideal. The reactions will still take place with water in the sediments, she adds, "but the process is more efficient if the olivine is on the surface".

The speed of these reactions is just one of several factors that will determine whether green beaches can actually help to cool the planet, and some scientists have already turned their backs on olivine out of fears that it takes too long to break down. Andrews acknowledges such uncertainties, saying it could take anywhere from 15 years to more than 500 years for the olivine to dissolve at North Sea Beach, according to Vesta's estimates. Quantifying that dissolution rate — and what the company can do to optimize it — is "at the heart of our R&D programme", she says.

Others worry about the potential environmental impacts of large-scale deployment. Even without factoring in the energy emissions, Vesta estimates that removing one tonne of CO_2 from the atmosphere requires around 1.4 tonnes of olivine depending on the location, which would entail large-scale mining operations. Nor will it be easy to extrapolate the potential impacts on ecosystems, including the dangers of heavy metal contamination, from such a small project.

"Vesta has had pretty good results so far with a small amount of olivine, but what happens when we start scaling up?" asks William Burns, co-director of the Institute for Carbon Removal Law and Policy at American University in Washington DC. "I think we need more research into the potential risks."

Speed troubles

Such fears have helped to push a Canadian company, Planetary Technologies based in Dartmouth, towards magnesium hydroxide, better known as milk of magnesia and marketed as an over-the-counter antacid for human consumption. More importantly, the product is already used to reduce the acidity of treated wastewater from sewage plants, so the process is known and the infrastructure to apply it is available worldwide.

The magnesium hydroxide particles are suspended in a slurry that provides a kind of timed release of alkalinity that could help to avoid a potential pitfall from rapid release into the ocean. Experiments in the laboratory and in ocean enclosures suggest that a spike in alkalinity can lead to supersaturation, causing solid carbonate minerals to precipitate out of the seawater (J. Hartmann *et al. Biogeosciences* **20**, 781–802; 2023). When that happens, it reverses the chemistry by removing alkalinity, which increases ocean acidity and can even lead to the release of CO_2 emissions from the ocean, says Andreas Oschlies, an oceanographer at the Helmholtz Centre for Ocean Research Kiel (GEOMAR) in Germany.

"We think using magnesium hydroxide hits this sort of sweet spot where we can add a lot of alkalinity, but it won't have an immediate impact and will take some time to dissolve," says Greg Rau, a biogeochemist at the University of California, Santa Cruz, and co-founder of Planetary Technologies.

The company released four tonnes of commercial-grade magnesium hydroxide last year into wastewater from a sewage treatment plant in Cornwall, UK, that travels through an 11-kilometre pipe to the sea. An as-yet-unpublished, independent analysis suggests that alkalinization began with acidic wastewater in the pipe and continued after the water entered the ocean, Rau says.

Green olivine crystals can be seen in the middle of a sediment core.

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The problem is that conventional methods for making magnesium hydroxide are energy intensive, so much so that last year's release in Cornwall barely broke even in terms of carbon emissions, according to the company's calculations. To become carbon negative, Rau says the company is turning towards a naturally occurring form of magnesium hydroxide called brucite and developing its own technology for purifying a clean version of the mineral from mining waste.

Planetary Technologies had to postpone its plans to conduct a second release in Cornwall this year after public protests arose regarding the release of brucite, which was mined in China.

Beginning in September, the company is planning a series of releases in cooling water from a power plant in Nova Scotia involving both commercially available magnesium hydroxide and brucite mined in China. That brucite would lead to a real CO_2 drawdown from the atmosphere. But it comes with further doubts about efficacy because it reacts more slowly than commercial magnesium hydroxide and it might settle in the sediments, according to Fennel.

The experiments will help researchers to tackle what might be the largest scientific challenge facing ocean alkalinization technologies: quantifying its impact in the field. Adding alkalinity and calculating a theoretical CO_2 transfer from the atmosphere into the ocean is easy, but the reality is that this transfer will occur only if the newly alkaline seawater remains at the surface and in contact with the air above, says Fennel. "If it gets drawn down into the ocean, then we might not get the benefit for another 1,000 years."

Fennel is conducting an independent assessment of Planetary Technologies' release in September; she will use a high-resolution geochemical model to help trace the alkalinity in an effort to pin down where it goes and how much CO_2 is actually pulled out of the atmosphere. This work will take place through a new international consortium she is leading, called Ocean Alk-align. The project launched this month with $11 million from the Carbon to Sea Initiative, a non-profit science programme co-founded by Meta's former chief technology officer Mike Schroepfer.

The consortium will assess the potential and the dangers of large-scale atmospheric CO_2 removal using ocean alkalinization with models and field experiments. "Neither the ocean models nor the observational tools that currently exist were designed with CO_2 removal in mind," says Antonius Gagern, executive director of the Carbon to Sea Initiative based in Washington DC, which has collected $50 million from various philanthropic foundations for research into ocean alkalinization over the next five years. "They have to be built."

Oschlies says private-sector interest could be a boon to research in this area, but only if science comes before profits. "We will probably learn the most from failures, but companies have to tell success stories," he says. "What we need is transparency."

Back on North Sea Beach, Chang says the sudden interest in ocean-based climate solutions has opened up a wealth of opportunities for scientists. She jumped from academia to the private sector in hopes of making a difference. "When was the last time venture capitalists needed to employ chemical oceanographers?" she says.

Just don't ask her if she thinks the project is going to work. Sitting on the beach, watching her crew extract another sediment core, Chang says her job is to determine how much CO_2 is absorbed over what time period — and to say if the numbers don't pan out.

"I'm looking for a real solution," Chang says.

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