Carbon on the Rocks

Researchers Analyze Conditions for Greenhouse Gas Capture on Rock-Amended Ag Lands

Barbra Rodriguez

Whether it's the craggy rocks of Asia's Gobi Desert, or the giant red buttes in Utah's Monument Valley, panoramic vistas like these have natural weathering processes over millennia to thank for their distinguishing features. Scientists have known for decades that rock weathering–the natural breakdown of minerals in mountains and soils–absorbs carbon dioxide from the atmosphere, and are now exploring negative emissions technologies that mimic this mineralization process to address climate change.

Berkeley Lab researchers in the national laboratory's Earth and Environmental Sciences Area (EESA) are investigating suitable silica-based rocks that would be finely ground and peppered across a corn field or other agricultural landscape to speed up carbon dioxide absorption using these enhanced rock-weathering technologies.

About 40 percent of U.S. lands are used for agriculture, as is more than half the land worldwide. In addition, plenty of rocks could work for enhanced weathering, given that Earth's crust is mostly made up of silica-based minerals. "We basically have an unlimited amount of rock that will weather anyway," said Peter Nico, acting director of Berkeley Lab's Energy Geosciences Division, "so this has a huge built-in potential to scale up compared to other negative emission technologies."

"If India, China, the U.S., and everywhere else applied enhanced weathering on half their croplands, we could sequester about **2 billion tons of carbon dioxide a year**," added EESA Research Scientist Bhavna Arora, who directs the Energy Geosciences Division's Carbon Removal and Mineralization Program.

Understanding Weathering Fundamentals

The urgency of our climate crisis means the details of using the promising weathering approach must be quickly mapped out, however.

Berkeley Lab scientists have been conducting modeling and other experiments since spring 2021 to identify the best land-based conditions for maximizing enhanced weathering. Beyond helping fight global warming, the approach could also benefit farmers.

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> *applied enhanced weathering on half their crop lands, we could sequester about* ***2 billion tons of carbon dioxide a year****," added EESA Research Scientist Bhavna Arora.*

For one thing, amending fields with rocks is "land-sparing," as Arora calls it. "Enhanced weathering can work right alongside other negative emission technologies, without interrupting farming activities and with the potential to improve crop yields."

Farmers typically increase production numbers by applying fertilizers that contain lime, which lowers soil acidity. But these fertilizers contain nitrogen that metabolizes into nitrous oxide, another greenhouse gas.

Farmers use lime fertilizer on wheat crops to enhance production. Credit: Shutterstock

Adding ground-up rocks would still alkalinize fields while avoiding this conundrum, and potentially increase yields, as has occurred in early field studies in Sweden and elsewhere. In part, the rocks contain trace metals and other elements that enhance plant growth. Research has also suggested that amending soils with crushed rock can improve soils' surface cohesion, which benefits plant development and growth. Topsoil erosion is happening globally, Arora said, making this no small matter.

Modeling Optimum Conditions

Before enhanced weathering can fulfill its potential, though, the best parameters need to be determined for its land-based use (while scientists elsewhere study sea-based approaches). Computer simulations of fosterite rocks for five years, which were led in 2021 by former EESA research scientist Hang Deng, have helped reveal what matters broadly.

Using data from different soil plots at an agricultural site in Modesto, California, as the starting point, Deng modeled weatherization at either a silty (clay-based) loam or a sandy loam field plot. The winner was the sandy loam due to its larger particles that permit water and air to infiltrate the soil more easily, also allowing in an unlimited amount of CO_2.

When weather conditions were held static, the size of the rocks used to capture carbon as either magnesium carbonate or calcium carbonate also had a big impact. The simulation showed that rocks which were ten times smaller, or one meter across, doubled the enhanced weathering rate over five years, because the smaller chunks had more surface area for CO_2 molecules to attach to. But this accelerated weathering approach currently has a mid-range price among NETs that are being developed, so Arora is tweaking parameters beyond rock size.

A challenge of surface-based approaches to carbon sequestration is that weather and other conditions can vary considerably in California and elsewhere. The original lab models assumed that the same temperatures occurred all year, and the same amounts of water (either 200 or 2,000 millimeters, or roughly 8 to 79 inches) rained down over that time span. Using daily temperature and rain field data obtained from the Modesto site,

The Enhanced Weathering project team checking out the mesocosm setup. From left to right, Hanna Breunig, Cristina Castanha, Ricardo J.E. Alves, Patricia Fox, and Kateryna Zhalnina. Photo Credit: Bhavna

Arora is refining the model to include such real-world conditions, while extending the studied time window out to up to a century.

Arora.

So far, the results have been surprising, with the silty loam, which drains water more slowly, working better for weathering than sandy loam. The silty loam maximized CO_2 sequestration during wetter winter months rather than during the dry, warmer conditions that tended to dominate in Modesto at the times studied. “You’d expect the process to happen better in summers because heat helps break down rocks faster, but water’s presence turns out to have such an important role in CO_2 mineralization.”

Rocking It in the Field

To focus on the initial parameters of interest, the original lab simulations also ignored the role that microbes associated with plant roots might play in altering rock weathering. So, Arora's team has begun studying what happens inside thick-walled polyvinyl chloride (PVC) chambers embedded into a research plot on the Berkeley campus.

As plants grow up naturally in the soil that is topped with quartz rocks (from the Working Lands Innovation Center at UC Davis), sensors have been in place to monitor conditions such as rainwater amounts and temperatures down to a depth of roughly 19 inches (50 centimeters). Porous bags of a rock-degrading bacteria were added atop the rocks on some of the tubes in March, to see how they impact the weathering process in the mesocosms (“middle-sized worlds”).

This mesocosm experiment is designed to understand how conditions like rainwater and temperature, in addition to rock-degrading bacteria, may impact weathering processes. Photo Credit: Bhavna Arora.

"How the microbes respond is a big, big question for these rock amendments," said Arora, "and that may vary by depth, and by the type of agricultural environment.

Future plans include widening the computer modeling lens to incorporate statewide soil data, performing studies on site at Berkeley Lab using a fabricated ecosystem called the SMARTSoils testbed, and studying rock mineralization at rice fields of the Working Land's fuel station in Davis.

"Once we have enough confidence in our current study results," Arora said, "we have good working relationships with farmers and communities to be able to extend the rock weathering studies beyond the current scales."