New 'lab on a chip' may accelerate carbon storage efforts

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Scientists at Stanford University have developed a new solution for the challenge of making sure that when carbon dioxide (CO_2) is injected underground, it actually stays put.

For decades, climate models have predicted that extreme heat waves of the sort experienced by millions of people this summer would become far more common at the levels of planet-warming gases now present in Earth's atmosphere. As emissions and temperatures continue to rise, there is growing scientific consensus that countries will need to actively remove and manage CO_2 for the world to avoid warming beyond the threshold of 1.5 degrees Celsius above pre-industrial levels.

One widely studied method for keeping removed carbon out of the atmosphere long-term involves injecting CO_2 into rock formations deep underground. But there are still questions to be worked out.

"Injection of carbon dioxide in storage formations can lead to complex geochemical reactions, some of which may cause dramatic structural changes in the rock that are hard to predict," said Ilenia Battiato, the study's primary investigator and an assistant professor of energy resources engineering at Stanford's School of Earth, Energy & Environmental Sciences (Stanford Earth).

Chain reactions

Earth scientists for years have simulated fluid flow, reactions, and rock mechanics to try to predict how injections of CO_2 or other fluids will affect a given rock formation.

Existing models, however, don't reliably predict the interplay and full consequences of geochemical reactions, which often produce tighter seals by effectively plugging pathways with dissolved minerals—but can also lead to cracks and wormholes that may allow buried carbon dioxide to affect drinking water or escape to the atmosphere, where it would contribute to climate change. "These reactions are ubiquitous. We need to understand them because they control the effectiveness of the seal," Battiato said.

One of the chief modeling challenges centers on the wide range of time and spatial scales over which interacting processes unfold simultaneously underground. Some reactions fizzle out in less than a second, while others continue for months or even years. As reactions progress, the evolving mix and concentration of various minerals in any given patch of rock, and changes to the geometry and chemistry of the rock surface, influence the fluid chemistry, which in turn affects fractures and possible pathways for leaks.

Lab on a chip

The new solution, described Aug. 1 in *Proceedings of the National Academy of Sciences*, uses a microfluidics device, or what scientists often refer to as a "lab on a chip." In this case, the researchers call it a "rock on a chip," because the technology involves embedding a tiny sliver of shale rock into a microfluidic cell.

To demonstrate their device, the researchers used eight rock samples taken from the Marcellus shale in West Virginia and the Wolfcamp shale in Texas. They cut and polished the slivers of rock to bits no bigger than a few grains of sand, with each one containing varying amounts and arrangements of reactive carbonate minerals. The researchers placed the samples into a polymer chamber sealed in glass, with two tiny inlets left open for injections of acid solutions. High-speed cameras and microscopes allowed them to watch step by tiny step how chemical reactions caused individual mineral grains in the samples to dissolve and rearrange.

The idea of miniaturizing research that once required large labs cuts across Earth sciences, biomedicine, chemistry, and other fields, said study co-author Anthony R. Kovscek, the Keleen and Carlton Beal Professor at Stanford Earth and a senior fellow at Stanford's Precourt Institute for Energy. "If you can see it, you can describe it better. These observations have a direct connection with our ability to assess and optimize designs for safety," he said. Today, Kovscek says geologists on drill sites may examine rocks under a microscope, but no current technologies approach the level of detail possible with this new device: "Nothing of this sort exists for really looking at how the grain shapes are changing."

Optimizing for safety

Improving reactive transport models is a matter of growing urgency, given the role of carbon removal in government plans for addressing climate change and the hundreds of millions of dollars now flowing to the nascent technology from private investors. Existing projects for removing CO_2 directly from the atmosphere are operating only at pilot scale. Those that catch emissions at the source are more common, with more than 100 projects in development worldwide and the U.S. government now preparing to spend $8.2 billion through the bipartisan infrastructure bill on carbon capture and storage from industrial facilities.

Not all carbon storage plans involve burying carbon underground. Those that do involve geological storage, however, could be aided and possibly made more stable and secure with the new Stanford technology. "Researchers need to incorporate this knowledge in their models to make good predictions about what's going to happen once you inject CO_2, to make sure it stays there and doesn't do strange things," Battiato said.

Looking ahead, Battiato and colleagues plan to use the same platform to study geochemical reactions triggered by injections of waste water from oil production, desalination plants, or industry, as well as hydrogen, which figures into U.S. and EU plans for slashing emissions by 2050. Although underground hydrogen storage is often cited as a promising solution to the steep and persistent challenge of ensuring safe storage of the highly flammable gas at large scale, testing it out at even pilot scale will require better screening tools and understanding of biogeochemical reactions.

More information: Probing multiscale dissolution dynamics in natural rocks through microfluidics and compositional analysis, *Proceedings of the National Academy of Sciences*, 2022.
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