SOLVING THE CARBON STORAGE GAP WITH OCEAN-BASED ENHANCED WEATHERING REACTOR TECHNOLOGIES

Martin Van Den Berghe, CEO of Cytochrome, explains how to solve the carbon storage gap with ocean-based Enhanced Rock Weathering reactor technologies

The Intergovernmental Panel on Climate Change and the International Energy Agency state that carbon management technologies must take place rapidly and scale up several orders of magnitude to achieve net-zero goals by 2050. [1] The de-facto model for carbon dioxide (CO_2) sequestration involves capturing it either from point-source emissions or through direct air capture, and then transporting it to well-injection sites for geological storage.

While the capture part of the equation already leverages relatively mature technologies and vectors for implementation at scale, the storage of CO_2 is still a significant challenge. Most regions worldwide do not have suitable geological formations for CO_2 injection, and existing well injection sites are severely geographically constrained and ultimately limited in their storage capacity.

Thus, most CO_2 emitters have no locally available storage options and are forced to transport their CO_2 to distant storage sites, whether by pipelines, ships, or both. Additionally, well injection efforts to date have shown to have high risks of CO_2 leakage & groundwater contamination and can experience early closures. [2, 3] They also require perpetual (i.e. centennial timelines) monitoring to ensure CO_2 doesn't leak and remains stored.

Also, geological storage requires high-purity CO_2, a technical necessity that adds a costly energetic burden on top of transport and well-injection processes. In fact, these steps of CO_2 purification, transport, and injection can represent up to 50% of the total cost of the carbon sequestration process. [2] Thus, the added costs of these energy-intensive workflows, long-term monitoring necessities, and leakage risks make well injection a prohibitively ineffective storage solution.

Plus, the market reality very clearly shows that global CO_2 capture capacity is far ahead of existing storage capacity. It is projected to be double that of global well injection capacity over the next few decades. [4–6]

Simply put, geological storage is an inadequate strategy for permanent carbon storage as it is technologically risky and cost-ineffective, and its capacity can't possibly meet the global market demand for CO_2 storage. The world clearly needs a storage option that can safely and cost-effectively store billions of tonnes of low-purity CO_2 per year.

What is Enhanced Rock Weathering?

Enhanced Rock Weathering (ERW) is a method of carbon sequestration that involves generating excess alkalinity through the dissolution of specific minerals. This alkalinity reacts with CO_2 and transforms it into bicarbonate, an inert chemical very similar to baking soda. In this form, CO_2 can be sequestered into the oceans in a very stable way without generating ocean acidification for many tens of thousands of years. [7, 8]

Rock weathering is, in fact, a very well-known and understood natural phenomenon that is often called "Earth's thermostat", as it is one of the significant contributing mechanisms to maintaining Earth within a narrow, livable climate envelope despite natural fluctuations in climate forcings over billions of years. [9]

Through this process, ocean waters have become the largest carbon reservoir at Earth's surface, storing 87% of its total carbon budget, or over 18 times more carbon than the Earth's entire land-based biosphere. [10] However, at its natural pace, rock weathering works on a timescale of centuries to millennia, which is a bit too slow to address our current climate crisis effectively. Hence, ERW involves a range of engineered systems and protocols that can accelerate this natural phenomenon.

The types of rocks used in ERW include carbonate and ultramafic silicate minerals, which are extremely abundant around the world, very cheap to extract, and benefit from an extensive and very well-established supply chain as they are already common components of industries such as mining, smelting, refining and cement.

In fact, as much as 7 billion tonnes of alkaline materials are already being generated globally each year in the form of industrial by-products. These include slag from smelting, tailings from mines, and cement, lime, and various ash products. Combined, these industrial by-products have a carbon capture and storage potential of several billion tonnes of CO_2 per year [11], enough to make a severe, planetary-scale impact on anthropogenic climate change.

Ultramafic minerals such as olivine, or wastes like slag and tailings are particularly interesting in that they naturally contain ~ 0.1 – 0.5 wt.% valuable metals like nickel, cobalt and chromium, critical for batteries and electronics. Therefore, ERW offers the potential for their recovery as value-added products and can catalyze the development of a circular economy: utilizing industrial wastes as a feedstock for highly cost-effective and safe carbon capture and storage and recovering strategically essential metals for the electric transition.

One model for ERW includes spreading alkalinity-generating minerals in chemically active environments such as beaches or agricultural soils as the means to accelerate the natural reaction. This approach can benefit from synergies with existing industries, such as agriculture and coastal engineering, but still faces limitations with weathering rates and complications with monitoring, reporting and verification (MRV), and fails to recover these valuable metals as they get released and lost into the environment. [12]

Cytochrome's approach to ERW

At Cytochrome, our approach to ERW is to catalyze the weathering reaction within a self-contained catalytic reactor chamber that can accelerate the mineral – CO_2 reaction by two orders of magnitude. This innovative approach involves reacting these minerals with CO_2 through an engineered mineral slurry, and leveraging cutting-edge developments in geochemistry and synthetic biology, thus catalyzing the formation of high concentrations of alkalinity and dissolved bicarbonate at ambient temperatures and pressures.

With this approach, even low-purity CO_2 can be utilized and transformed to stable bicarbonate within the reaction chamber, and is then released back to the ocean for permanent storage. Controlling the seawater flow conditions enables simple, low-cost MRV methodologies and the recovery of critical metals released from mineral dissolution. Lastly, this approach removes the need to purify, transport and inject CO_2, thus eliminating high-energy workflows and decreasing the total cost of carbon sequestration by up to 50%.

Decarbonization and carbon removal efforts

To conclude, decarbonization and carbon removal efforts represent a nascent trillion-dollar industry, yet the current carbon capture and geological storage model severely lacks the certainty and capacity to address our climate crisis effectively. Ocean-based ERW approaches offer a natural, highly synergistic and cost-effective opportunity.

Unfortunately, ERW efforts are operating as startups in a challenging financial environment, while hundreds of billions of dollars currently support a problematic geological storage option. Better support for ERW efforts – particularly with the scaling-up, permitting and industrial integration process, will greatly enable meeting net-zero 2050 goals.

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