UNLEASHING THE POTENTIAL OF BIOLOGY IN MINING AND ENHANCED ROCK WEATHERING BY BRIDGING THE ACADEMIC-INDUSTRY GAP

Martin Van Den Berghe, CEO of Cytochrome, along with Jayme Feyhl-Buska and Paul Reginato of Homeworld Collective, explore the potential of biology in mining and enhanced rock weathering by bridging the gap between academia and industry

Mineral dissolution in enhanced rock weathering (ERW) and mining technologies

Rock dissolution is well understood to be a core mechanism in keeping the Earth livable over billions of years. Natural rock weathering is often called "Earth's thermostat" because it regulates atmospheric carbon dioxide – storing it in the oceans as dissolved bicarbonate and in the geosphere as carbonate rocks. [1] Simultaneously, natural weathering provides dissolved nutrients essential for life. Rock dissolution processes have also long supported human societies and their ability to obtain metals as a critical component of mining and hydrometallurgy.

Recently, methods to further accelerate rock dissolution have emerged as a core innovation needed for carbon capture and storage applications for climate change mitigation and sustainable mining. Enhanced rock weathering (ERW) technologies aim to grow the fraction of CO_2 emissions that is offset by weathering, from ~3% at natural rates [2–4], to levels high enough to significantly mitigate modern climate change. In hydrometallurgy, accelerating mineral dissolution and recovering specific elements cost-effectively and sustainably is crucial for meeting the increasing critical mineral demands of the energy transition while coping with declining ore grades.

Biological processes accelerate mineral dissolution

Decades of academic work have demonstrated that various microbes have evolved to enhance rock dissolution, either to acquire the inorganic nutrients contained in the rocks or as a result of chemical byproducts of their metabolic processes. While these discoveries are fascinating from a geochemical and evolutionary standpoint, they also have profound implications as potential components of novel ERW and mining technologies. Ongoing and rapid innovations in synthetic biology and genomics now enable the genetic engineering of microbes to accomplish specific biochemical purposes, carrying with them a truly transformative potential for improving rock dissolution technologies and industrial processes.

The potential of biology in mining and ERW

In the case of mining, many metals are locked into rocks that are prohibitively expensive to process or require processing techniques with severe health and environmental risks. Biologically-enhanced metal recovery techniques can prepare the ore for downstream operations that would not be otherwise economically or physically feasible. Genetic engineering can also enable a highly efficient process of selective adsorption for critical rare earth elements from leachates, removing the need for expensive solvents. [5]

In the case of ERW, biological tools can make it possible for microbes to continuously secrete metal-scavenging siderophore molecules, thereby dramatically increasing their ability to accelerate rock dissolution and increasing rates of carbon capture and storage by an order of magnitude. [6–8] Such increases in process efficiencies are what many ERW technologies need to have a real chance at reaching their full potential and scaling up to gigatons of CO_2 per year.

Academic-industry gaps inhibit progress

Despite these exciting developments, knowledge of microbe-mineral interactions often remains restricted to academic spheres, and most industry leaders remain unaware that potentially transformative biological solutions exist for the challenges they face. Few geobiologists are taught that scaling a technology in industrial environments carries major constraints relating to techno-economics, permitting, energy, or footprint requirements related to deploying a novel technology at scale.

Conversely, the industry community is typically unaware that some well-characterized geobiological mechanisms have the potential to increase process efficiencies by an order of magnitude or more or may not understand how to integrate geobiology in a way that captures its benefits while avoiding interference with other process components. In our view, integration of geobiology into ERW and mining innovation is urgently needed to pursue viable technologies for climate change mitigation and the energy transition.

The cultural divide between geobiology and industry makes productive research and development (R&D) discourse challenging. There is also a lack of accessible knowledge resources, tools, and research infrastructure at the intersection of the two communities, reinforcing their isolation. As a result, well-meaning geobiologists may focus on research goals that do not address real challenges critical to deploying and commercializing a technology at scale, while industry may be overly dismissive or skeptical of the possible role of geobiology in their processes.

Community building and research tools to enable research and development

Eliminating these barriers will require multi-pronged work across the community, knowledge transfer and scale-up, and funding. A comprehensive process of inter-community engagement and working relationships can help build connections through structured discourse amongst innovators in geobiology and industry. Such engagements should include dedicated workshops, meetings, and mechanisms to facilitate the transfer of knowledge, expertise, and personnel across these communities. Fostering community-wide engagement requires better support for both infrastructure and institutions that can bridge the gap between geobiology and industry.

To this effect, Homeworld Collective has developed a Problem Statement Repository for sharing community-led descriptions of high-priority actionable research problems, which can be addressed by researchers applying for Homeworld's Garden Grants. Homeworld Collective provided funding for several ERW projects and is seeking to expand this kind of support towards biomining research.

Homeworld Collective has also developed an open-source techno-economic analysis tool for biomining, which is designed to help innovators estimate cost factors and identify economic limitations or opportunities relating to novel technologies early in the development process in such a way as to reflect industrially relevant operating conditions.

On the other hand, R&D facilities and institutions supporting technology validation for industrial applications are a necessary link that is too often missing. Yet this kind of infrastructure and support is critical, since demonstrating a technology in an industrially-relevant context can transform early-stage concepts with limited investment potential into high-value assets that can attract significant investment and industrial partnerships. For climate technology startups like Cytochrome, being able to demonstrate unit efficiency increases by a factor of 5 or 10 through existing geobiology tools can be catalytic in developing its full potential.

Building upon Homeworld Collective's trailblazing work, one can envision institutions akin to incubators. These could support R&D for sectors like climate technologies and sustainable mining by providing space for knowledge transfer and housing physical infrastructure that enables technology validation in high-fidelity prototypes, leading to valuable advancements in technology readiness. Such institutions can serve as fertile grounds, fostering the cutting-edge R&D needed to meet global net-neutral and circular economy goals.

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