ENHANCED MINERALIZATION

WHAT IS ENHANCED MINERALIZATION?

Enhanced mineralization (also referred to as "enhanced weathering" or "CO_2 mineralization") accelerates the natural processes by which various minerals absorb carbon dioxide (CO_2) from the atmosphere. This natural weathering process converts about one billion tons each year of atmospheric CO_2 into rocks, providing reliable, long-term storage. Enhancing or speeding up this weathering process would begin with the mining of specific kinds of rock, such as olivine or basalt. One prominent proposal for implementation would involve grinding those rocks into powder and spreading the powder over soils, where it would react with the air to form carbonate minerals that provide reliable, long-term carbon storage. Other proposals involve exposing the powdered rock to seawater or to streams or pure CO_2 from power plants or direct-air-capture facilities.

A related option, **ocean alkalinization**, involves spreading alkaline substances, such as lime, over the ocean, where it would absorb CO_2. This is often classified as a type of enhanced mineralization, but it offers the added benefit of directly counteracting ocean acidification by increasing the pH of seawater.

CO-BENEFITS AND CONCERNS

+ **Improved soil quality**: depending on the type of rock used, spreading powdered rock over soils could improve soil quality by adding nutrients.
+ **Countering ocean acidification**: ocean alkalinization would directly counteract ocean acidification, thereby protecting coral reefs and marine ecosystems

− **Concerns associated with mining**: most enhanced mineralization requires extensive mining and processing of raw materials, which raises a range of local environmental and health concerns
− **Soil and groundwater contamination**: depending on the type of rock used, heavy metals could leach from powdered rock into soils or groundwater

GOVERNANCE CONSIDERATIONS

- ☐ **Encouraging adoption**: incentives would be needed to encourage widespread adoption in a range of different contexts.
- ☐ **Monitoring, verification, and reporting**: processes, standards, and technologies need to be developed to reliably measure carbon sequestration.
- ☐ **Ensuring environmental and social sustainability**: policies are needed to ensure the environmental and social sustainability of mining, processing, transport, and application of minerals across complex supply chains.
- ☐ For **cross-cutting considerations**, see the What Is Carbon Removal? fact sheet on our web site.

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TECHNOLOGICAL READINESS

The basic chemistry of enhanced mineralization is well understood, and the technology to mine, grind, and disperse rock is widely available. Research on enhanced mineralization as a form of carbon removal, however, remains in comparatively early stages. Much more work needs to be done before it is ready for widespread deployment.

POTENTIAL SCALE AND COSTS

Because it enables permanent sequestration in non-saturable sinks, the long-term potential for enhanced mineralization is very large. A recent expert assessment estimates that enhanced mineralization could be scaled up to capture **2–4 billion metric tons of CO_2 ($GtCO_2$) per year by 2050**, with rates of **more than 20 $GtCO_2$ per year theoretically possible by 2100**, with **another 1–27 $GtCO_2$ per year possible through ocean alkalinization**. Estimates of the **cumulative potential in this century range from 100 $GtCO_2$ to 367 $GtCO_2$**, with even more possible through ocean alkalinization. Cost estimates vary widely, **from less than $50 per ton of CO_2 sequestered to more than $200 per ton**.

FURTHER READING

Jens Hartmann et al., "Enhanced Chemical Weathering as a Geoengineering Strategy to Reduce Atmospheric Carbon Dioxide, Supply Nutrients, and Mitigate Ocean Acidification," *Reviews of Geophysics* 51, no. 2 (2013): 113–49, https://doi.org/10.1002/rog.20004.

Ilsa B. Kantola et al., "Potential of Global Croplands and Bioenergy Crops for Climate Change Mitigation through Deployment for Enhanced Weathering," *Biology Letters* 13, no. 4 (2017), https://doi.org/10.1098/rsbl.2016.0714

Phil Renforth and Gideon Henderson, "Assessing Ocean Alkalinity for Carbon Sequestration," *Reviews of Geophysics* 55, no. 3 (2017): 636–74, https://doi.org/10.1002/2016rg000533.

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