

Carbon mineralization for CO₂ removal from air and permanent solid storage

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Carbon mineralization involves reaction of CO₂ with silicate, oxide and hydroxide materials to form solid carbonates. Typically, Ca-, Mg- and Na-rich minerals and feedstocks are considered. Natural carbon mineralization is spontaneous during weathering of ultramafic (mantle peridotite, olivine-rich intrusions) and mafic (basalt, gabbro) rocks, which are far from equilibrium with the atmosphere and surface waters. Near the surface, they constitute a huge reservoir of chemical potential energy. Accelerated pathways harness this energy to capture and/or store CO₂ via reaction with rocks, “alkaline industrial wastes”, and oxide/hydroxide derived from sediments (limestone, dolomite, magnesite, evaporites), with achievable fluxes ~GtCO₂ per year.

Different pathways (1-3) are envisioned, with varied purposes (CO₂ removal from air, CDR, and/or solid CO₂ storage, SCS). (1) “Ex situ” mineralization involves mining and transport of feedstock to a site of CO₂ capture, where they are combined in high PT vessels for SCS. (2) “Surficial” mineralization involves mine tailings, industrial wastes, and oxide/hydroxide materials, reacting with CO₂ in air (CDR ± SCS) or captured CO₂ (SCS), at ambient PT. Surficial mineralization can be locally focused (tailings, waste heaps) or via dilute dispersal over soils or the ocean. (3) “Subsurface” mineralization involves reaction of rocks in place with circulating surface water for CDR + SCS, or with CO₂-enriched aqueous fluids or super-critical CO₂ (scCO₂) fluid for SCS.

Cost, area and rate estimates for most pathways exist. Ex situ mineralization is expensive and difficult to scale, but value-added products may reduce net cost. SCS in tailings and subsurface minerals may cost ~2x “conventional” scCO₂ storage in pore space, but some mineralization methods are low risk, requiring less site characterization, monitoring and verification. CDR using tailings or subsurface mineralization is challenging due to slow reactions and transport limitations, though methods intermediate between CCS and CDR (using gas with ~10-20% CO₂) should be investigated. Diffuse dispersal of reactive material over soils or the oceans offers relatively low-cost CDR, but verification and monitoring are challenging. CDR via looping of oxide/hydroxide derived from geologically abundant materials offers a simple, robust, fast, relatively inexpensive method to produce pure CO₂ (Direct Air Capture, DAC) but requires offsite storage.