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A cradle-to-grave perspective on monitoring, reporting, and verifying carbon dioxide removal through enhanced weathering

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Although reducing greenhouse gas emissions must be the central aim of climate mitigation efforts in the coming decades, the need for carbon dioxide removal (CDR) has become more widely accepted as a component of meeting climate goals. As a result, venture capital, philanthropic funds, and federal support are all being leveraged to bring a range of terrestrial and marine CDR pathways to scale. In parallel, there are concerted efforts to develop models of soil, river, and ocean biogeochemistry that could potentially be used to quantify carbon removal for real-world deployments. Here, we review key issues associated with empirical verification and model-based quantification of carbon removal through enhanced weathering on managed lands, foregrounding challenges and uncertainties in empirical measurement and predictive modeling of: (1) feedstock dissolution; (2) cation storage, transport, and removal; (3) additionality and background carbon fluxes in river/stream systems; and (4) uptake and recycling of inorganic carbon and alkalinity in the coastal ocean. We argue that although there are major challenges to empirically verifying end-to-end carbon removal through enhanced weathering at scale, the current generation of models used to represent soil, river, and ocean biogeochemistry are also not sufficiently comparable or well-validated to produce compensatory claims for offsetting fossil fuel emissions. We call for transparent, coordinated near-term efforts to generate publicly available field trial data for evaluating uncertainties in empirical verification techniques, together with broad-based efforts to openly evaluate uncertainty and predictive skill in state-of-the-art soil, river, and ocean biogeochemistry models. Lastly, we discuss potential tradeoffs between acceptable uncertainty in monitoring, reporting, and verifying enhanced weathering in ton-for-ton offsetting frameworks and the potential environmental or socioeconomic co-benefits associated with responsible deployment of enhanced weathering as an agronomic practice.