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A framework for understanding efficiency losses of Ocean Alkalinity Enhancement

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Ocean alkalinity enhancement (OAE) is a promising carbon dioxide removal (CDR) pathway, with the potential for Gt-scale CO2 sequestration and storage. However, the efficiency of OAE, in terms of how much atmospheric CO2 is sequestered and stored per unit of alkalinity added to seawater, remains poorly constrained. Efficiency at a given timepoint after alkalinity addition is often described as $\eta_{CO2}(t) = \Delta DIC(t)/\Delta Alk$. Most studies quantifying η_{CO2}, however, consider only ocean circulation and gas exchange kinetics. In real applications, net CO2 uptake, and the ultimate efficiency of a given alkalinity intervention, depends on additional factors. Here, we present a framework itemizing the full spectrum of potential loss factors. We identify four broad loss categories arising from: 1) Incomplete mineral dissolution, 2) Alkalinity loss to solids (mineral precipitation and cation exchange), 3) Subduction of unequilibrated water, and 4) Indirect impacts on organic and inorganic carbon cycling (including additionality concerns). Within each category, we identify specific subcategories that must be independently investigated and quantified. We summarize the knowledge base for each loss pathway and propose metrics to facilitate consistent data reporting. Our intention is that this framework will help streamline scientific research and reporting, with the goal of identifying important loss pathways, and ultimately constraining the net efficiency of proposed OAE deployments.