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Perspectives and challenges of marine carbon dioxide removal

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The Paris Agreement to limit global warming to well below 2^{o}C requires drastic reductions in greenhouse gas emissions and the balancing of any remaining emissions by carbon dioxide removal (CDR). Due to uncertainties about the potential and durability of many land-based approaches to deliver sufficient CDR, marine CDR options are receiving more and more interest. The current state of knowledge is discussed, regarding the potentials, risks, side effects as well as challenges associated with technical feasibility and responsible governance of marine CDR. A range of biotic and geochemical approaches is covered, and marine oxygen is used as key parameter for addressing possible side effects on marine ecosystems. A comparison with internationally prohibited direct injection of CO_2 into seawater provides additional guidance for assessing marine CDR methods. It is argued that geochemical methods may have higher CDR potential and substantially smaller side effects than biotic methods, challenging the often-stated view that 'nature-based' approaches should be preferred to 'technological' ones.