



Experimental investigation of multiple industrial wastes for geochemical carbon dioxide removal strategies

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The Paris Agreement goal to limit the global average temperature increase to below 2°C cannot be achieved without atmospheric CO₂ removal (CDR) on the order of tens of gigatonnes per year by 2100. Such a formidable challenge requires an urgent assessment of all possible routes to CDR, as further delayed mitigation will have an increasingly damaging effect on the environment. The challenge is pertinent to industrial sectors which produce several Gt of CO₂ per year and are susceptible to financial impacts due to nascent carbon taxes worldwide, and other negative environmental impacts brought on by the generation of vast amounts of solid and liquid waste materials (e.g., rock cuttings and overburden, fine mine tailings, glassy slags, fly ashes and desalination reject brines). Geochemical CDR strategies in such industrial wastes, where the natural process of rock weathering and carbonate precipitation is utilised to uptake CO₂, is a potentially significant CDR approach for bicarbonate (alkalinity) and carbonate generation, requiring material assessment and enhancement schemes to fully realise the high removal potential.

The DETAILS project (Developing enhanced weathering methods in mine tailings for CO₂ sequestration; Marie Skłodowska-Curie grant agreement ID: 101018312) is exploring the CO₂-water-solid waste material reactivity of a range of mine tailings, slags and fly ashes, sourced from industrial centres globally. The range of materials includes those considered to be chemically and mineralogically promising for CDR (e.g., mine tailings derived from olivine dunite, Ni sulphide and diamond kimberlite operations, carbonate marble fines), materials with limited or unknown CDR potential (e.g., Al-bauxite-related red muds, borate tailings, ilmenite tailings, products from SO₂ processing, copper smelting produced slags and combustion fly ashes), and materials generally considered unfavourable (e.g., Cu and fluorite tailings). For all materials, the key to CDR strategy utilisation is the ability of favourable minerals to undergo significant dissolution for alkalinity generation and possible subsequent carbonation, on appropriate human timescales (e.g., seconds up to decadal), either naturally or through achieving enhanced rates of dissolution and precipitation.

Changes to water chemistry through reactions with CO₂ and powdered material samples were monitored throughout the experiment. These include changes to pH, alkalinity, silica, Ca²⁺ and Mg²⁺ cations, (Mg-Ca cations required for reactions with CO₂ to produce stabilised bicarbonate and

carbonate ions). Preliminary results reveal that Mg- and Ca-bearing minerals within some wastes react with CO₂ to form alkalinity, suggesting potential for CDR strategies. Methods to increase reaction rates will be explored, such as a microbially-induced pH switch to increase the kinetics of mineral dissolution and mineral carbonation (e.g., oxidation and reduction reactions associated with microbial metabolisms active in sulphur and nitrogen cycling). A better understanding of reaction kinetics for a wider range of industrial wastes will help future projects to confirm or reconsider the viability of materials for CDR strategies, and to better identify opportunities for upscaled pilot schemes with further implemented geochemical CDR methods to speed up reaction kinetics.