Chemical and Biological Catalytic Enhancement of Weathering of Silicate Minerals as Novel Carbon Capture and Storage Technology

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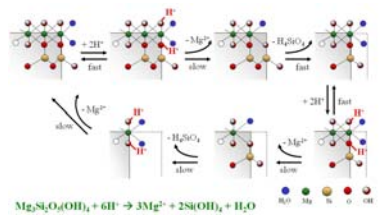
Element 1: Chemically Enhanced Mineral Dissolution

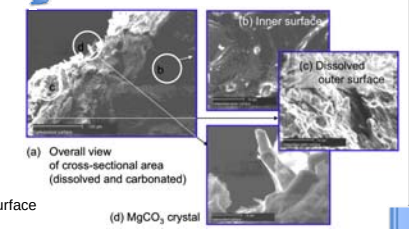
Goal: Enhance mineral dissolution rate through chemical activation of the silicate surfaces and collect kinetic data for reactor design

Challenges:
- Collect accurate and reproducible mineral dissolution rate data
- Maintain high dissolution rate of mineral particles
- Prevent formation of diffusion limiting silica surface layer or enhance removal of such layer

Approach:
- Differential bed kinetics
- Harness silica chelating chemistry

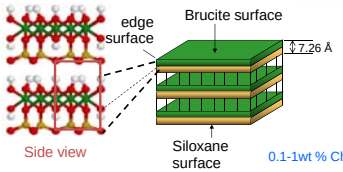


Dissolution of serpentine in nature



Formation of diffusion limiting layer

Structure of serpentine



pH 2-10
T 25-200ºC
0.1-1wt % Chelating Agents

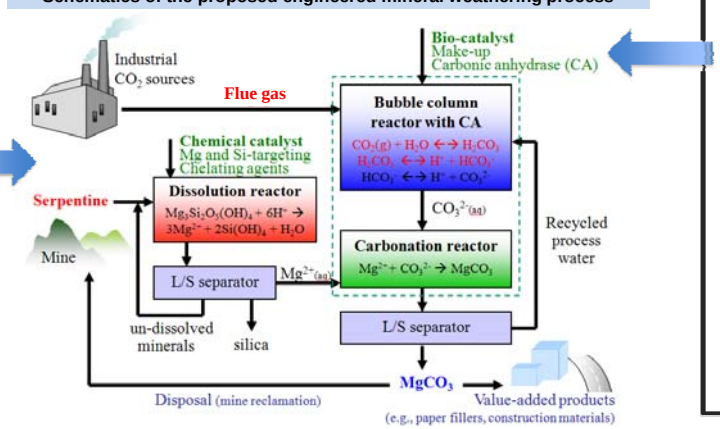
Photo of high pressure differential bed reactor

(1) Jorgensen. Dissolution kinetics of silicate minerals in aqueous catechol solutions. European Journal of Soil Science (1976)
(2) Park & Fan. CO_2 mineral sequestration: physically activated dissolution of serpentine and pH swing process. Chem. Eng. Sci. (2004)

Project Overview

Carbon mineralization is a creative and novel approach that will provide a transformational solution for carbon capture and storage (CCS) that is truly safe and permanent by accelerating natural weathering process of silicate minerals. Its current shortcoming is slow mineral dissolution and CO_2 hydration kinetics. Recently we have made important advances in chemically activating dissolution of Mg-bearing minerals and the use of carbonic anhydrase in the carbonation process. Based on these findings, we propose to develop a novel carbon capture and storage technology by applying new Si-targeting chemical catalysts and engineered bio-catalysts (carbonic anhydrase). If successful, this cost-effective technology has the potential to significantly reduce carbon emissions from power plants without long-term monitoring needs.

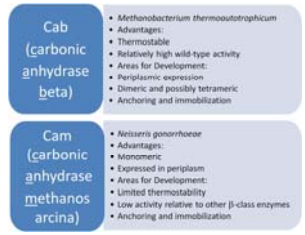
Schematics of the proposed engineered mineral weathering process



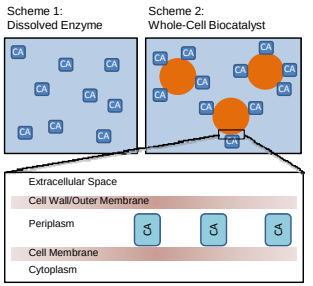
Element 2: Bio-catalyst Development

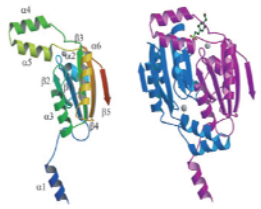
Goal: Develop a heterogeneous whole-cell biocatalyst based on carbonic anhydrase to increase the rate of CO_2 hydration in the aqueous phase

Challenges:
In the uncatalyzed conversion of CO_2 (g) into carbonate salts, the hydration of CO_2 is the rate-limiting step. This can be remedied by the incorporation of an enzymatic catalyst (e.g., carbonic anhydrase).



Approach:
Express enzyme in the periplasmic space of the cell, and anchor to the cell membrane such that when the cell wall is permeabilized or removed, carbonic anhydrase can readily access the CO_2.
- Synthesis and evaluation of CA as dissolved enzyme and whole-cell bio-catalyst (see scheme 1 & 2)
- Thermal and pH stabilities of engineered CA





(3) Smith, K.S. and Ferry, J.G. "Prokaryotic carbonic anhydrases". FEMS Microbiology Reviews 24 (2000) 335-366.
(4) Strop, P., et. al. "Crystal structure of the "cab"-type b Class Carbonic Anhydrase From the Archaeon Methanobacterium thermoautotrophicum" J. Biol. Chem. 276 (2001) 10299-10305.

Element 3: CO_2 Hydration & Carbonation

Goal: Design and operation of carbonation reactor for the evaluation of engineered CA

Deliverables
- Development of CA recycle scheme
- Optimization of reaction conditions for product formation, and thermal and pH stabilities of CA

Element 4: Overall Process Integration

Goal: Integration of mineral dissolution and carbonation units and evaluation of the overall process

Deliverables:
- Evaluation of continuous fluidized bed reactor system compared to differential and batch systems
- Operation using simulated flue gas

Element 5: Process & Systems Optimization

Goal: Energy integration and optimization of operating conditions for improved economic feasibility

Deliverables:
- Completion of overall mass and energy balance
- Quantification of parasitic energy demand

Element 6: LCA & Economic Assessments

Goal: Perform life cycle and economic assessment for the entire process

Deliverables:
- Assessment of costs and environmental benefits of mineral carbonation technology on power generation