Techno Economic Analysis Development for Enhanced Weathering and Marine Carbon Dioxide Removal

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Background

According to the National Academy of Sciences (NAS) and International Panel on Climate Change, decarbonization alone will not be sufficient to reach current climate goals; several gigatons of CO_2 will need to be removed from the atmosphere to achieve these goals [1]. Enhanced weathering and marine carbon dioxide removal (CDR) are emerging technologies that can aid in the direct removal of CO_2 from the atmosphere. This poster presents on NETL's active work on the techno-economic analysis (TEA) of enhanced weathering and marine CDR. Financial assumptions will be common with already released Direct Air Capture Case Studies [2,3].

What is Enhanced Weathering?

"Weathering" is the natural breakdown of alkaline rocks in the presence of rainwater, temperature changes, and/or living organisms. Weathered rocks contain silicate, hydroxide, and carbonate minerals that react with CO_2 during this process to produce aqueous bicarbonate ions.

$$M(OH)_2 + 2CO_2 \rightarrow M^{2+} + 2HCO_3^- \qquad MSiO_3 + 2CO_2 + H_2O \rightarrow M^{2+} + SiO_2 + 2HCO_3^- \qquad MCO_3 + H_2O + CO_2 \rightarrow M^{2+} + 2HCO_3^-$$

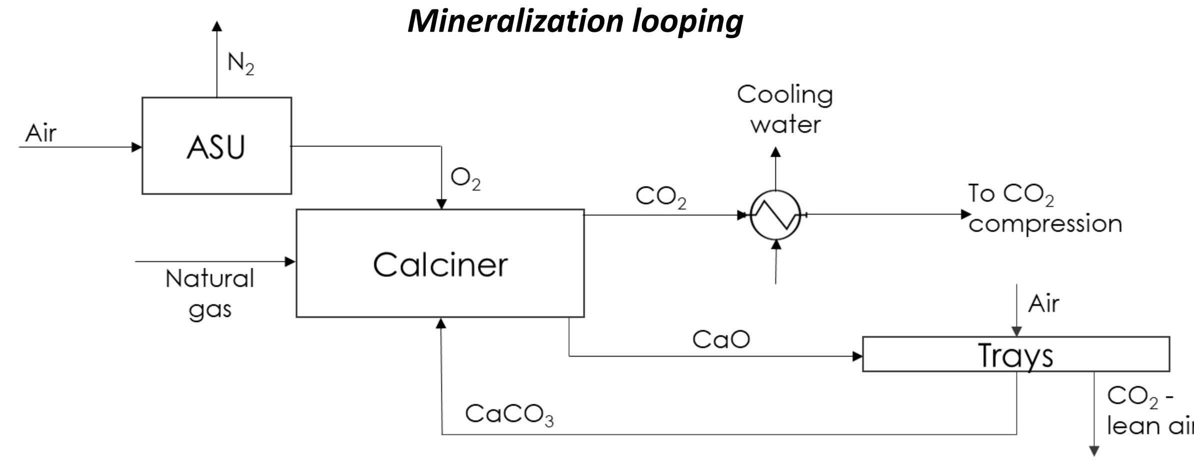
where M is typically Ca or Mg

The removed atmospheric CO_2 in the form of aqueous bicarbonate ions is eventually transported to the oceans where it can remain in solution for >100,000 years. Enhanced weathering accelerates this process by mining and crushing alkaline rocks to increase the exposed surface area. The crushed rocks can be spread across coastal regions, tropical areas, and agricultural fields where pH, temperature, and water exposure can enhance weathering rates.

NETL's Enhanced Weathering TEA Approach

Terrestrial enhanced weathering (TEW)

Mineralization looping



This study will assess terrestrial enhanced weathering (TEW) and mineralization looping. TEW involves distributing mined and crushed rock or industrial waste materials that react with CO_2 on land where the material will be weathered. Mineralization looping involves calcining carbonate-rich rock to produce a reactive oxide. The oxide is then spread on fields or set in trays to carbonate. Finally, the carbonated material is collected and calcined, with CO_2 as a product.

Enhanced weathering base cases and sensitivities

Parameter	Case 1: TEW, Igneous Rock		Case 2: TEW, Waste Material		Case 3: Mineralization Looping, Limestone	
	Base	Sensitivity	Base	Sensitivity	Base	Sensitivity
Capacity, tonne rock/yr	250,000	100,000–500,000	18,000	3,000–35,000	-	-
Efficiency, %	-	-	-	-	85%	20–90%
Weathering potential, kg CO_2/tonne rock	800	300–1,200	500	200–1,190	1,165	1,140–1,190
Material cost, $/tonne rock	25.0	5–45	0	-35–35	24	10–435
Comminution energy, kWh/tonne rock	20	8-300	-	-	10	3–100
Energy cost, $/MWh	60	25–300	60	25–300	60	25–300
Energy source capacity factor, %	85%	20–100%	85%	20–100%	85%	20–90%
Application cost, $/tonne rock	6	3–15	6	3–15	-	-
Natural gas cost, $/MMBtu	-	-	-	-	4.42	4–10

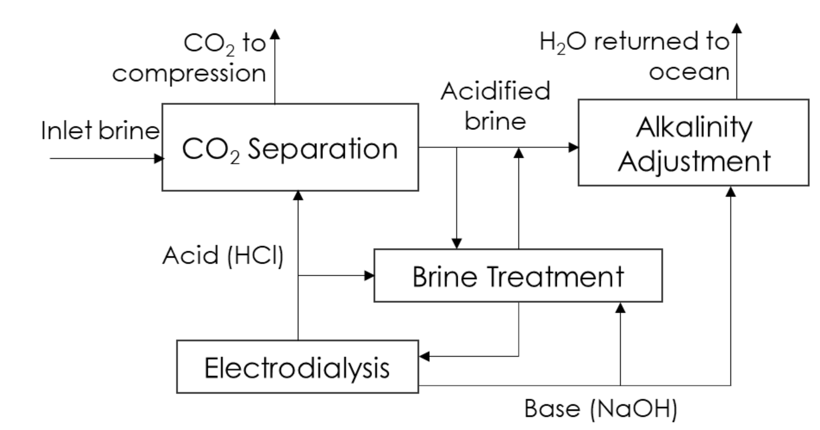
All cases will be assessed under ISO conditions. Case 1 will use igneous rock; specifically, dunite and basalt, the two most common rocks in literature. Case 2 will use industrial waste; specifically, cement kiln dust and biomass ash since they are readily available and demonstrate high weathering potentials. Case 3 will use limestone/lime since it is widely available in the United States. For all cases, a base case will be developed based on the average parameters, and sensitivities will be performed on these parameters to account for the different materials or scenarios.

What is Marine CDR?

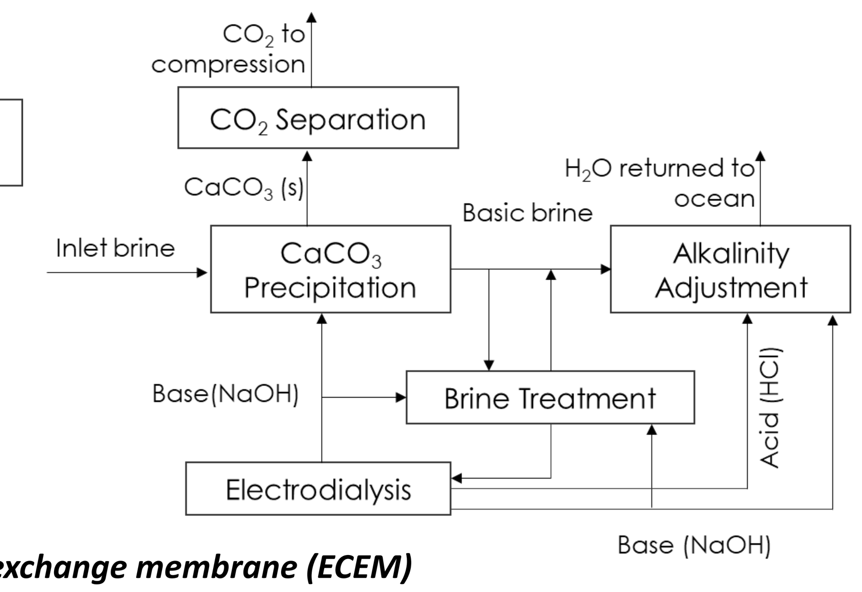
Oceans can be viewed through the CDR lens as a large natural CO_2 reservoir, storing about 20–40% of anthropogenic emissions. The ocean holds roughly 40–60 times as much carbon as the atmosphere. CO_2 in the ocean is often referred to as dissolved inorganic carbon (DIC). DIC is the sum of dissolved CO_2, bicarbonate(HCO_3^-), and carbonate (CO_3^-) in seawater. This makes the ocean an ideal resource for CO_2 removal through marine CDR. NAS defines marine CDR as indirect CO_2 removal from the atmosphere via an enhancement of the downward air–sea flux of CO_2 from the atmosphere to the surface ocean. The removed CO_2 is then stored in marine or geological reservoirs for >100,000 years.

NETL's Marine CDR TEA Approach

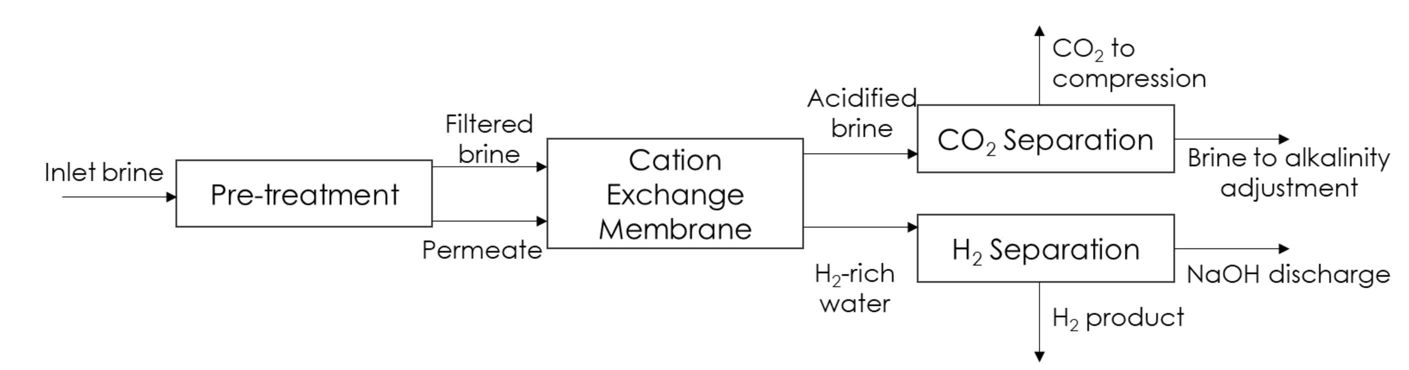
MEB1: BPMED acid pH shift



MEB2: BPMED base pH shift



Electrolytic cation exchange membrane (ECEM)



This study assesses two different types of electrochemical marine CDR: bipolar membrane electrodialysis (BPMED) and electrolytic cation exchange membrane (ECEM). Both technologies involve extracting CO_2 from ocean water in a definable process and maintaining chemical and mineral balances within the ocean water so that marine life is unaffected.

Marine CDR base case cost references

Parameter	Value	Cases
CO_2 Separation Unit, $/unit	6,930	All
Bipolar Membrane Electrodialysis, $/unit	422,700	MEB1, MEB2
Cation Exchange Membrane, $/m^2	50	ECEM
Mixing Tanks	Scaled from NETL data	All
Reverse Osmosis Unit	Scaled from NETL data	ECEM
Balance of Plant	Scaled from NETL data	All
Brine Discharge, $/MGD	0.5	All
Electricity Price, $/MWh	60	All
Membrane Replacement Costs, % of initial costs	40	All
Waste Disposal	Scaled from NETL data	All
Maintenance and Labor	Scaled from NETL data	All

For all three cases, the base plant will be located along the Florida coast. In addition, a sensitivity analysis will be conducted to assess the merits of stand-alone vs. co-located plants. Stand-alone plants pump ocean water directly into the capture system, while co-located plants are integrated with desalination plants or other industrial processes that draw large quantities of seawater. Additional sensitivities include plant size, electricity source and carbon footprint, and capacity factor. The impact of locating the process in California will also be addressed through this work.

References: [1]"Carbon Removal." World Resources Institute. https://www.wri.org/initiatives/carbon-removal (accessed July 20, 2023). [2] J. Valentine, A. Zoelle, "Direct Air Capture Case Studies: Sorbent System," National Energy Technology Laboratory, Pittsburgh, PA, July 8, 2022. [3] T. Fout, J. Valentine, A. Zoelle, A. Kilstofte, M. Sturdivan and M. Steutermann "Direct Air Capture Case Studies: Solvent System," National Energy Technology Laboratory, Pittsburgh, May 15, 2020.

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