Screening Analysis of Terrestrial Enhanced Rock Weathering of Igneous Rocks and Industrial Waste Materials

Research & Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

Sarah Leptinsky[1,2]; Sally Homsy[1]; Hari Mantripragada[1,2]; Tim Fout[3]

[1]U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), Pittsburgh, PA; [2]NETL support contractor; [3]DOE Office of Fossil Energy and Carbon Management, Washington DC

Background

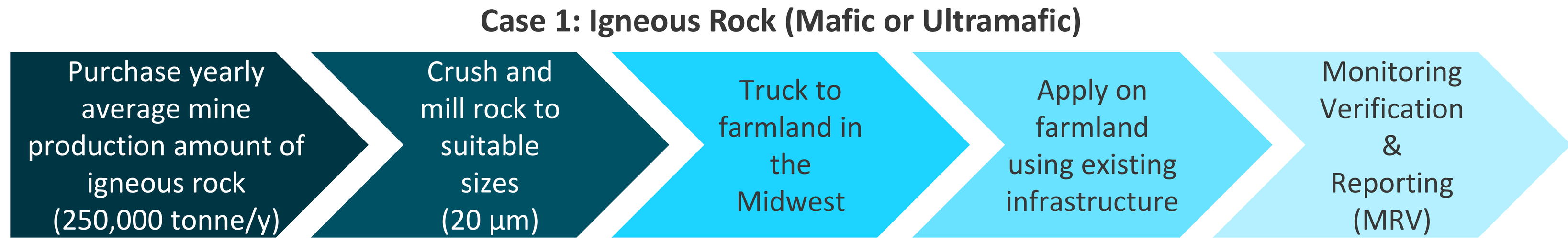
Enhanced rock weathering (ERW) is an emerging carbon dioxide removal technology. Alkaline rock weathering is a naturally occurring atmospheric CO_2 sink. In the presence of rainwater, temperature changes, and/or living organisms, silicate, hydroxide, and carbonate minerals react with CO_2 to produce aqueous bicarbonate ions, which are eventually transported to the oceans and can remain in solution for >100,000 years. ERW aims to harness and accelerate this naturally occurring process. This is accomplished by mining and crushing alkaline rocks to increase the exposed surface area, and spreading this material across coastal regions, tropical areas, and agricultural fields where pH, temperature, and water exposure can enhance weathering rates.

Design Basis

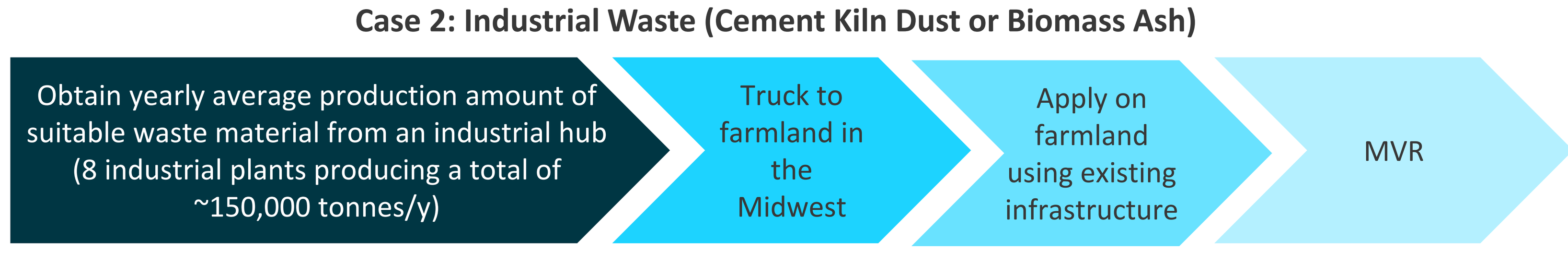
This poster reports on an NETL screening level techno-economic assessment of ERW. Two base cases are developed representing average parameters for two different alkaline material sources. Sensitivities are performed to account for different materials and scenarios. Material is re-applied to the same farmland (midwestern ISO location) on a yearly basis, and the project has a 30-year life. Financial assumptions are in line with already released direct air capture (DAC) case studies [1, 2].

Comminution energy requirement is calculated using literature reported correlations, and associated equipment costs are scaled from legacy NETL studies (analogous equipment for material handling, storage, and grinding). Transport cost is calculated as a function of material quantity and transportation distance.

Case 1: Igneous Rock (Mafic or Ultramafic)



Case 2: Industrial Waste (Cement Kiln Dust or Biomass Ash)



ERW base cases

	Case 1: Igneous Rock	Case 2: Waste Material
Initial rock use, tonne	250,000	144,000 (18,000/plant)
Rock size, micron	20	-
Specific surface area, m^2/kg	1.69	2
Comminution energy, kWh/tonne	57	-
Weathering potential, kg CO_2/tonne	800	600
Weathering rate, mol/m^2/s	1×10^{-10}	1×10^{-9}
Material coverage, kg/m^2	21	21
Average farm, hectares	153	153
Material transport, miles	250	250
Material price, $/tonne	25	0
Transport price, $/tonne	35	35
Material application price, $/tonne	6	6
Purchased power, $/MWh	67	67
MVR, $/hectare/year	150	150

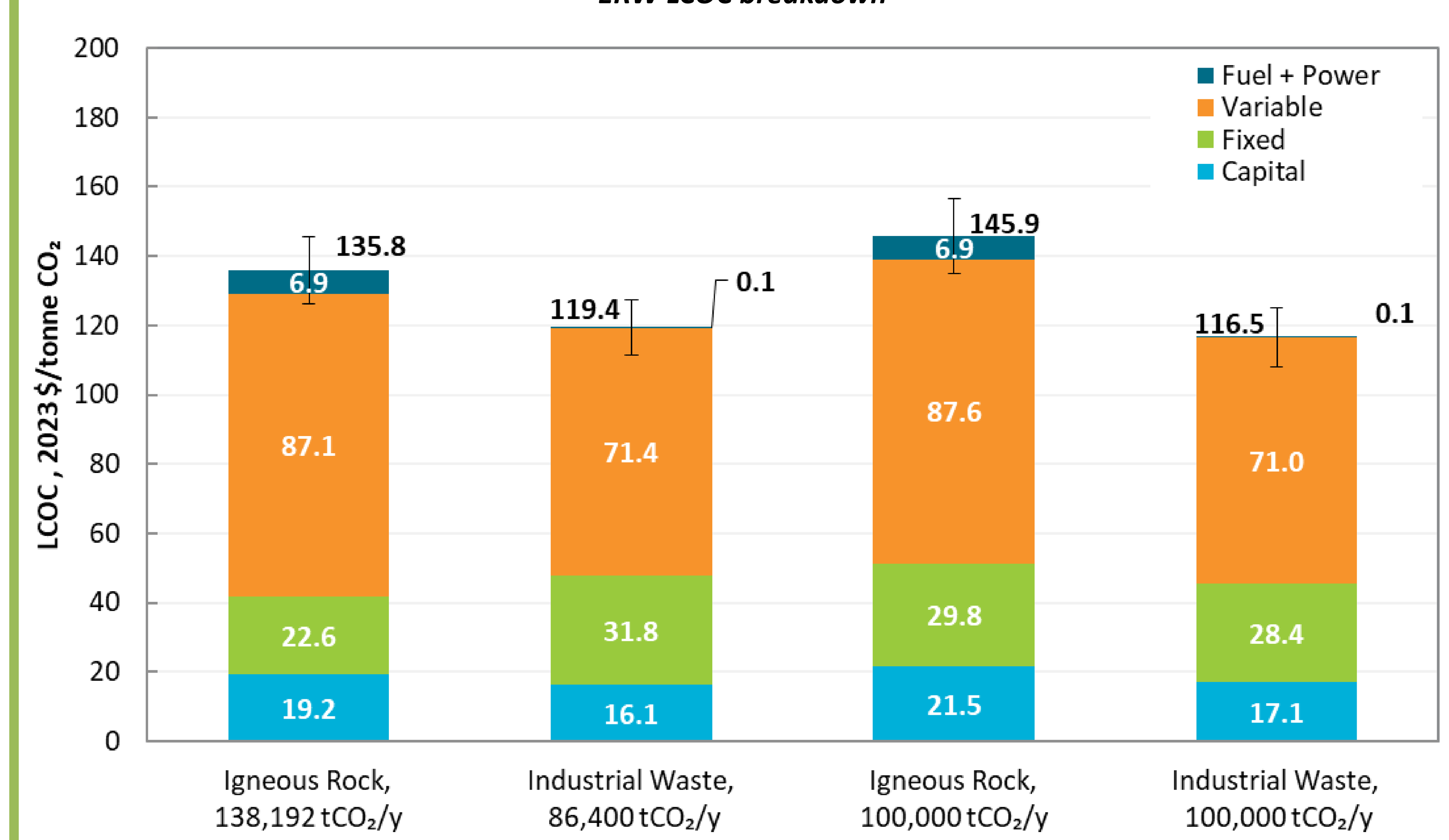
Base Case Results

ERW performance results

	Igneous Rock	Waste Material
	Case 1	Case 2
CO_2 captured, tonne/yr	138,192	86,400
Initial rock use, tonne	250,000	144,000
Rock makeup, tonne/yr	172,740	144,000
Auxiliary load, MWh/yr	14,148	-
Land needed, hectares	1,190	686
# of farms	8	5

The levelized cost of CO_2 captured (LCOC) is calculated by dividing ERW process annualized capital, operation and maintenance (O&M), power, and fuel purchase costs by the total amount of CO_2 captured from the atmosphere on a yearly basis. Costs are presented in May 2023 real dollars. The uncertainty of the capital cost estimates is +/-50 percent (consistent with the AACE Class 5 cost estimates). Variable cost (material cost, application cost, material transport cost, and MVR) is the largest contributor to the LCOC for both cases.

ERW LCOC breakdown



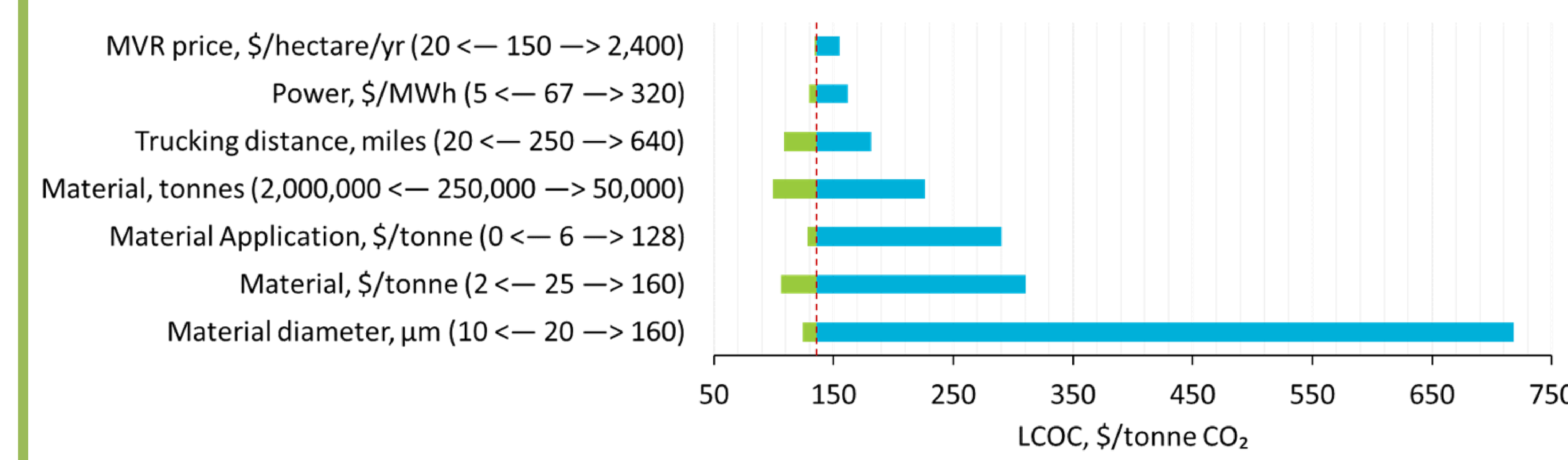
Conclusions & Resources

- Utilizing materials with high weathering potential in suitable locations can lead to relatively low levelized cost of removal (~$100-200/tonne CO_2 removed).
- NETL is publishing a detailed and transparent report summarizing the findings of the screening level techno-economic analysis. The report will also contain life cycle analysis details and report costs a CO_2 removal basis.
- Future work will aim to incorporate more specific design parameters related to technology, materials, and location.

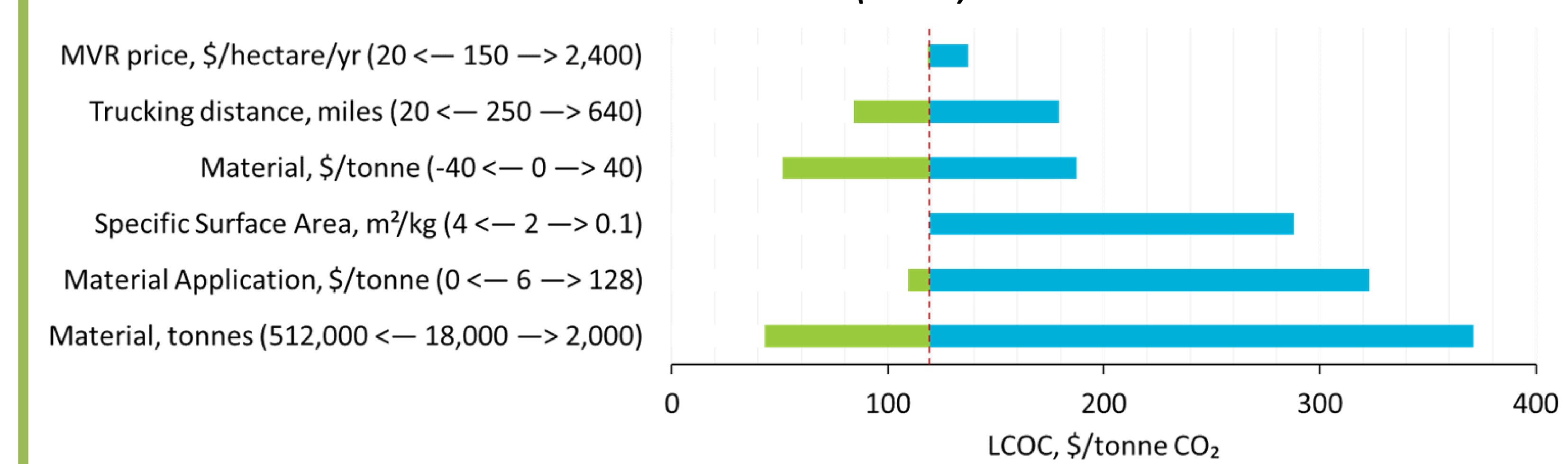
References: [1] J. Valentine, A. Zoelle, "Direct Air Capture Case Studies: Sorbent System," National Energy Technology Laboratory, Pittsburgh, PA, July 8, 2022. [2] T. Fout, J. Valentine, A. Zoelle, A. Kilstofte, M. Sturdivan and M. Steutermann "Direct Air Capture Case Studies: Solvent System," National Energy Technology Laboratory, Pittsburgh, PA, May 15, 2020

Sensitivity Analysis

ERW with igneous rock (Case 1) sensitivities



ERW with industrial waste (Case 2) sensitivities



The most impactful parameters on the ERW LCOC are the weathering potential and weathering rate. The weathering rate is highly dependent on the pH and temperature conditions of the application site, and the weathering potential is dependent on the composition of the material. Together, these parameters determine the efficiency of the capture system and, thus, impact the LCOC.

ERW with igneous rock (Case 1) LCOC ($/tonne of CO_2)

Weathering potential [kg CO_2/tonne]	Weathering rate [mol·m^{-2}s^{-1}] 1.E-08	1.E-09	1.E-10	1.E-11	1.E-12
200	--	--	--	--	--
300	316	316	362	1,673	14,759
400	237	237	272	1,255	11,069
500	189	189	217	1,004	8,855
600	158	158	181	837	7,380
700	135	135	155	717	6,325
800	118	118	136	627	5,535
900	105	105	121	558	4,920
1000	95	95	109	502	4,428
1100	86	86	99	456	4,025
1200	79	79	91	418	3,690
1,300	73	73	84	386	3,406

Mafic (300–1000); Ultramafic (1100–1,300)

ERW with industrial waste (Case 2) LCOC ($/tonne of CO_2)

Weathering potential [kg CO_2/tonne]	Weathering rate [mol·m^{-2}s^{-1}] 1.E-07	1.E-08	1.E-09	1.E-10	1.E-11
200	358	358	358	534	3,503
300	239	239	239	356	2,335
400	179	179	179	267	1,751
500	143	143	143	214	1,401
600	119	119	119	178	1,168
700	102	102	102	153	1,001
800	90	90	90	133	876
900	80	80	80	119	778
1000	72	72	72	107	701
1100	65	65	65	97	637
1,200	60	60	60	89	584
1,300	--	--	--	--	--

Biomass ash (200–700); Cement kiln dust (900–1,200)

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