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Using Waste Heat and CO_2 from (Bio)Energy Production to Enhance Rock Weathering: Geochemical Feasibility

Jim Amonette
jim.amonette@pnnl.gov

Pacific Northwest National Laboratory
& Washington State University

Bioenergy's Role in Soil Carbon Storage
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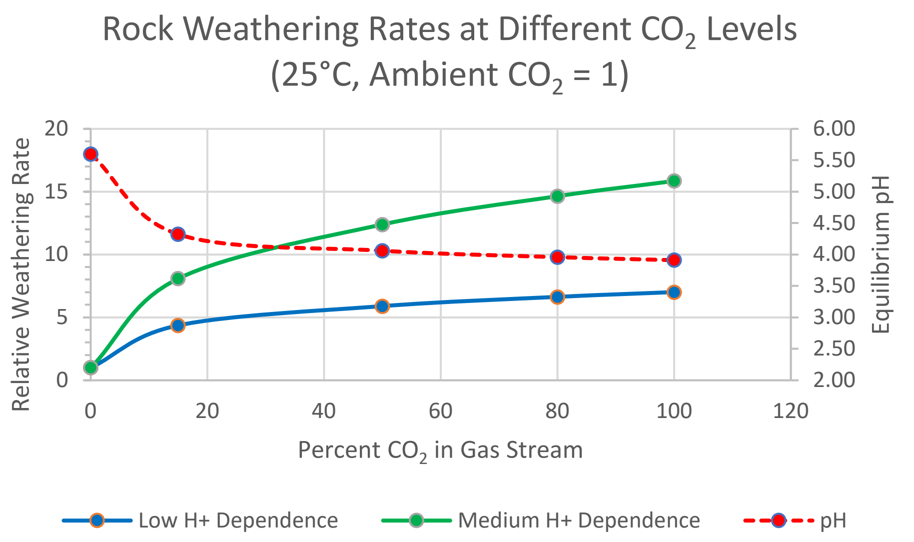
Concept

- Low-grade process heat (< 90°C) and exhaust CO_2 (~15% by volume) from small-scale pyrolysis/combustion systems is often wasted
- Natural weathering of (Ca,Mg) silicate rocks captures atmospheric CO_2 as aqueous bicarbonate ions and solid (Ca,Mg) carbonate minerals
- Weathering rates depend on acidity from CO_2 and increases with temperature
- This talk explores the potential increase in weathering rates (relative to ambient conditions) by applying waste heat and CO_2 to basalt rock weathering

Mineral susceptibility to acid-promoted weathering at 25°C

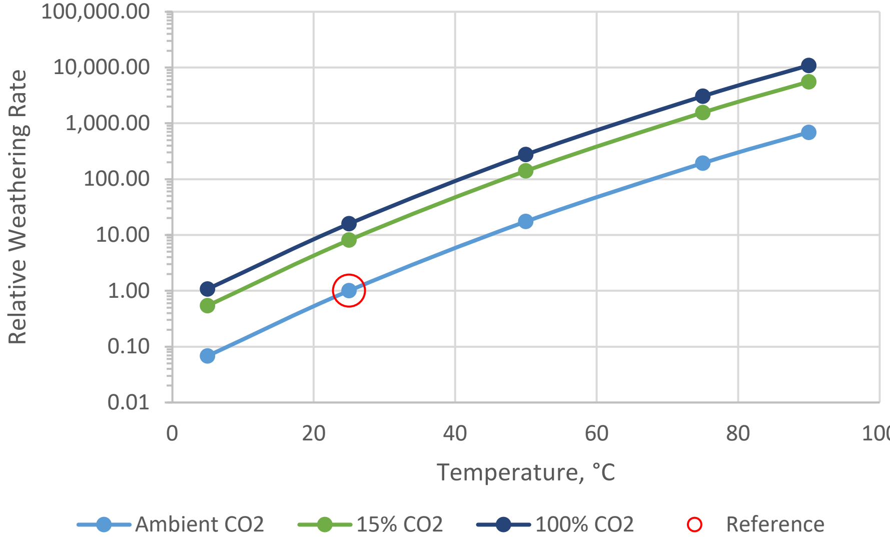
		Relative Weathering Rates	
%CO2	pH	0.5	0.71
0.0417	5.60	1	1
15	4.32	4.36	8.08
50	4.06	5.88	12.39
80	3.96	6.62	14.64
100	3.91	7.00	15.84



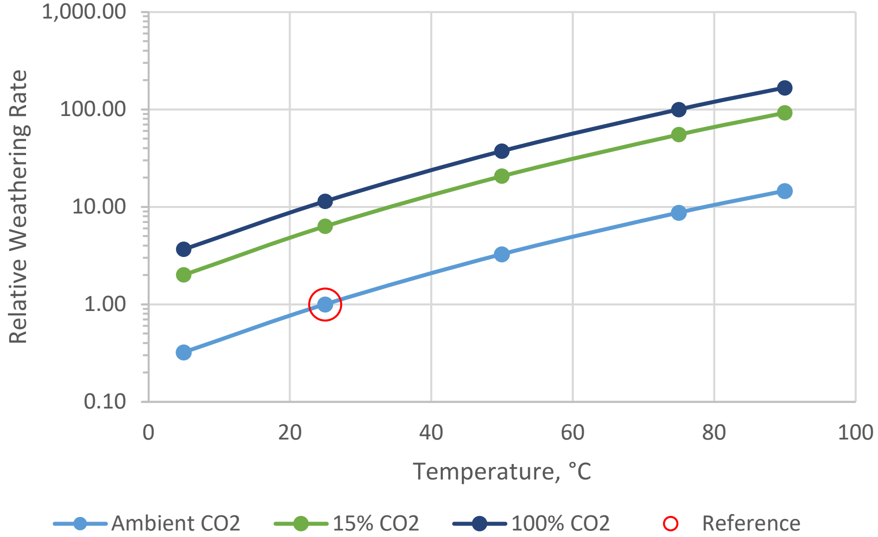
Calculated weathering rates for two common basalt minerals (diopside and labradorite) at elevated temperatures and CO_2 levels

	Relative Weathering Rates (Reference: 25°C, 417 ppm CO2)					
Temperature	Diopside			Labradorite		
(°C)	Ambient	15% CO2	100% CO2	Ambient	15% CO2	100% CO2
5	0.07	0.54	1.08	0.32	2.01	3.67
25	1.00	8.11	15.8	1.00	6.33	11.4
50	17.3	140	274	3.27	20.7	37.3
75	192	1555	3039	8.71	55.1	99.6
90	685	5553	10856	14.6	92.2	167

Diopside Weathering Rates at Different Temperatures and pH Levels
(Relative to 25°C and pH 5.60 from Ambient CO_2)



Labradorite Weathering Rates at Different Temperatures and pH Levels
(Relative to 25°C and pH 5.60 from Ambient CO_2)



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Discussion and Conclusions

- Weathering rates vary significantly with mineral type
- Enhancement by CO_2 alone is relatively modest
  - up to 15x at 25 °C
- Enhancement by temperature alone is very strong
  - up to 700x at ambient CO_2
- Diopside is easily weathered
  - 5500-fold enhancement (15% CO_2 at 90°C) suggests that the equivalent of **15 years of weathering** under ambient conditions can be accomplished in a single day
- Labradorite weathers more slowly
  - 90-fold enhancement (15% CO_2 at 90°C) suggests that **3 months of weathering** under ambient conditions can be accomplished in a single day
- Use of waste low-grade heat and CO_2 to enhance the weathering of basalt shows great promise for increasing the C-offset potential of bioenergy, biochar, and other thermal-energy production processes.

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Methods, References and Acknowledgments

Methods

Calculations were performed in a spreadsheet using Henry's Law and temperature-adjusted aqueous carbonate system speciation constants provided by Plummer & Busenberg (1982). Rate constants were determined using equations provided by Lewis et al. (2021) and mineral-specific acidic weathering parameters provided by Palandri & Kharaka (2004).

References

Lewis, AL, B Sarkar, P Wade, et al. 2021. *Applied Geochemistry* 132:105023.

Palandri, JL & YK Kharaka. 2004. *US Geological Survey Open File Report* 2004-1068.

Plummer, LN & E Busenberg. 1982. *Geochimica Cosmochimica Acta* 46:1011-1040.

Acknowledgments

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Contact

Jim Amonette jim.amonette@pnnl.gov 509-371-6381

Speaker Notes

Slide 1

Hi there. I'm Jim Amonette and would like to talk with you about an idea to combine two negative emission technologies for climate change mitigation (bioenergy/biochar and enhanced rock weathering). This talk explores the geochemical feasibility of such a combination.

Slide 2

The idea is to use the low-grade waste heat (after it has lost any steam production value) and the exhaust CO_2 (typically around 15% concentration by volume) to speed up the weathering rate of silicate rocks that contain Ca and Mg. This natural weathering reaction removes CO_2 from the atmosphere and captures it as aqueous bicarbonate ions (alkalinity) and also as carbonate mineral solids. The rate of weathering depends on the acidity of the solution, which increases with the CO_2 concentration, and on the temperature of the system. It also depends on the susceptibility of the minerals in the silicate rock to proton-induced weathering. I performed geochemical calculations to assess the feasibility of using this concept. On the right are some calculated data showing the increase in weathering rate at 25°C as a function of CO_2 concentration for minerals covering the range of proton-susceptibility for minerals commonly found in basalt, an abundant Ca/Mg bearing rock frequently used in enhanced rock weathering experiments. Depending on the mineral susceptibility, the rate of weathering increases between 7- and 16-fold in going from ambient levels of CO_2 to a pure CO_2 system. The data plotted below the table show the calculated decrease in pH with increasing CO_2 levels (red dashed line) and the relative increases in weathering rate for the range of minerals commonly found in basalt (blue and green solid lines). For all variables, the largest change is in going from ambient to 15% CO_2.

Slide 3

To explore the role of temperature in combination with CO_2, I selected two silicate minerals, diopside and labradorite, found in an Oregon basalt that I am currently experimenting with. For these calculations of relative weathering rates, I used a matrix of 5 temperatures (5, 25, 50, 75, and 90 °C) and 3 CO_2 concentrations (ambient, 15% and 100%) that covers the full range of interest. All rates were calculated relative to the reference conditions (ambient CO_2 and 25°C) and thus independent of any assumptions of reactive surface area. The rates shown are for situations far from equilibrium with the two silicates. The results, which differ substantially for the two minerals, show exponential increases in weathering rate as temperature increases and reproduce the relatively modest increases seen for CO_2 in the previous slide. The reference conditions are highlighted in orange in the table and by a circled symbol in the plots.

Slide 4

The results show distinct differences in the weathering rates of minerals, suggesting that any effort involving basalt weathering must take the mineralogical composition into account as shown in a recent paper by Lewis et al. (2021). The effect of temperature is much stronger than that of CO_2 concentration, with as much as a 700-fold difference in rate between 25°C and 90°C. Weathering rates using 15% CO_2 and 90°C are about 5500 times greater for the diopside and 90 times greater for the labradorite than those that would be achieved under ambient conditions. These rates double in going from 15% CO_2 to 100% CO_2, but suggest that for practical purposes, normal exhaust concentrations of CO_2 are adequate. The rate enhancements at 15% CO_2 and 90°C suggest that the equivalent of 15 years of weathering of the diopside could be accomplished in a single day using these waste products. For the labradorite, the equivalent of 3 months of weathering would be achieved. I conclude that use of waste heat and exhaust CO_2 from bioenergy/biochar and other thermal energy facilities to weather basalt rock can significantly expand their climate mitigation potentials well beyond that achieved by a linear combination of energy/biochar production and field weathering under ambient conditions. More research is clearly needed to demonstrate this synergy, but the feasibility seems good at this stage of investigation.

Slide 5

Here is a brief synopsis of the methods used for the calculations together with some relevant references. A portion of this work was funded by a BIOAg grant from the Center for Sustaining Agriculture & Natural Resources at Washington State University, with whom I have a joint appointment. I've also listed my contact information and would be happy to engage with you to explore further development of this concept.

Thank you for your attention!