Enhanced Weathering at the Energy Farm

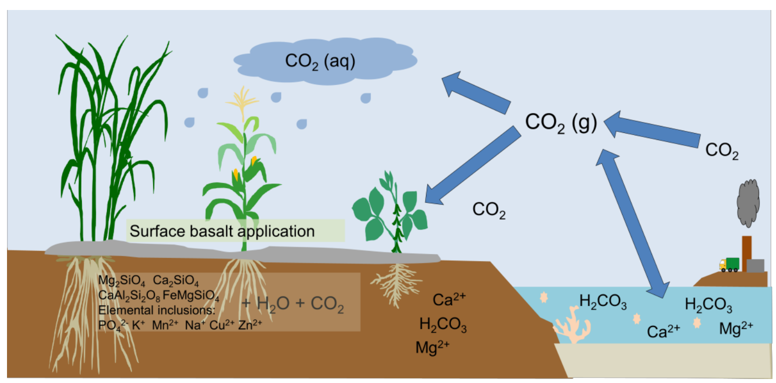
Combating atmospheric CO_2 from ground level

Terrestrial ecosystems play an important role in regulating the exchange of greenhouse gases between the land surface and the atmosphere. Intensive agriculture contributes ~14% of annual global greenhouse gas emissions, and management practices have enormous potential to alter this exchange.

We are investigating enhanced weathering as a method to combat rising atmospheric carbon. In enhanced weathering the natural capture of CO_2 during rock weathering is accelerated by applying ground silicate rocks (basalt) to agricultural soils. In the soil, temperature, moisture, microbial activity, and plant root exudates combine to decompose the parent rock material and result in the formation of calcium and magnesium bicarbonates, which raise soil pH and shift atmospheric carbon to the hydrosphere, where it can be transported downstream and ultimately sequestered as carbonates in the sea floor.

At the Energy Farm we are testing the scope and feasibility of enhanced weathering in both conventional and cellulosic bioenergy crops. We have applied 5 T/ha of finely ground basalt to research plots across the Energy Farm, tilled into corn/soy fields and surface-applied to miscanthus plots. Conventional bioenergy crops (corn and soybeans) raised for food and fuel represent the dominant ecosystem of the Midwestern United States, with over 90M acres of land devoted to their production. Cellulosic bioenergy crops including perennial miscanthus are a growing percentage of US land area, and have been identified as important agents of soil carbon conservation.

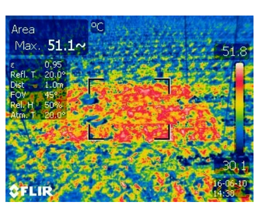
Miscanthus x *giganteus*, a perennial bioenergy crop.



A simplified weathering cycle for soil-applied basalt.

Applying the Science

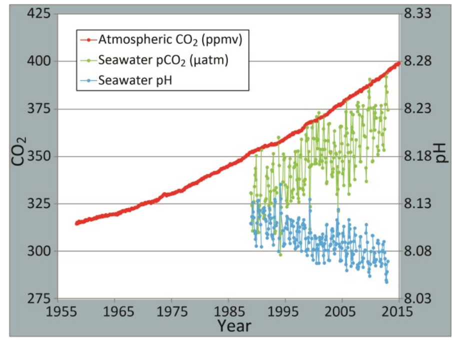
Finely ground basalt is applied using fertilizer or limestone spreading equipment and incorporated into conventional bioenergy crop plots during normal tillage operations. Basalt in cellulosic bioenergy plots is surface-applied. We monitor soil biogeochemistry, soil water chemistry, soil respiration, eddy covariance, and plant tissue chemistry and biomass measurements to monitor weathering rates and effects on soil and crops.



Atmospheric CO_2

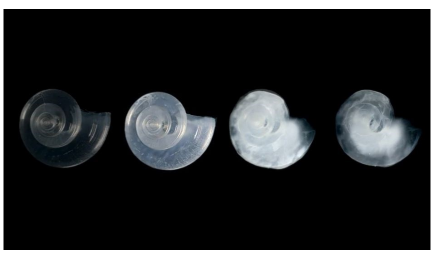
Atmospheric CO_2 has been steadily rising since the beginning of the Industrial Revolution, and is higher now than at any time in the last 400,000 years. Long term measurements taken at the Mauna Loa Observatory in Hawaii (right) show a steady increase. Atmospheric CO_2 is a result of both natural Earth phenomena (volcanic activity, microbial respiration) and anthropogenic activity (combustion of fossil fuels, soil disturbance, destruction of carbon-storing forests and vegetation).

In the atmosphere, CO_2 joins methane, nitrous oxide, and halocarbons as greenhouse gases, which absorb heat emitted from the Earth and reflect it back toward the planet's surface, creating the inhabitable atmosphere in which we live. An overabundance of these gases leads to a runaway greenhouse effect, where the Earth's atmosphere becomes like that of Venus.



Correlation between atmospheric CO_2 concentration measured at Mauna Loa and seawater CO_2 concentration and pH at nearby Station Aloha. (NOAA PMEL Carbon Program, adapted from RA Feely, 2008.)

Ocean Acidification



Pteropod shells over the course of 45 days in sea water at predicted pH for 2100. (David Liittschwager, National Geographic Images)

Earth's oceans absorb about 1/4 of the CO_2 released to the atmosphere each year, and as atmospheric CO_2 rises, ocean CO_2 rises, and pH falls (see graph above). While ocean absorption of CO_2 has a buffering effect that moderates atmospheric CO_2 levels, there are negative consequences to the oceans. According to NOAA calculations, ocean acidity has increased 30% since the beginning of the Industrial Revolution.

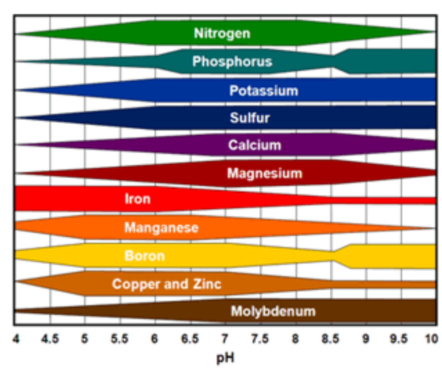
Rising CO_2 concentrations in ocean water may benefit photosynthetic algae and seagrasses, but the acidic environment produced by high CO_2 dissolves calcium-based shells and exoskeletons, harming shellfish, sea urchins, corals, and calcareous plankton (left).

Soil Fertility

The availability of soil nutrients for uptake by plants is affected by soil pH. Essential nutrients including nitrogen, phosphorus, potassium, and calcium become less available to plants as soil pH drops. Enhanced weathering consumes free protons during the formation of bicarbonate, which raises soil pH, and adds micronutrients and silica to the soil.

Increased soil fertility has the potential to support greater biomass production, which in turn may increase soil C through root and litter inputs from crops. The exudates of plant roots and the activity of mycorrhizal fungi in the soil are essential to the rock weathering process.

Additionally, excess nitrogen not taken up by plants is released from soils, and is an important contributor to greenhouse gases and atmospheric warming.



Relative availability of plant nutrients along a pH gradient. Increased metal availability at low pH can lead to metal toxicity, while both low and high pH limit the availability of essential nutrients.

Why Basalt?

Basalt has been chosen for enhanced weathering research at the University of Illinois due to widespread availability and chemical composition. Approximately 4.6% of Earth's terrestrial land area has exposed regions of basalt.

Various forms of basalt contain 8-20% Ca and Mg oxides by weight, and 1-2% potassium oxides and phosphates. Basalts are among the fastest-weathering silicate rocks, an important factor in producing a rapid effect on atmospheric CO_2 levels.

Why Agricultural Land?

The earth's terrestrial land area hosts 10-15M km^2 of agricultural land, much of which stand to benefit from added soil amendments. As the rate of basalt weathering in natural outcrops is limited by surface area, applying basalt across large regions of agricultural land maximizes the benefit from basalt application by exploiting the material's CO_2 capturing properties, buffering properties, and micronutrient composition simultaneously. Basalt can act as a rock fertilizer in agricultural land, reducing N loss, and providing elemental nutrients.

Plants and their symbiotic mycorrhizal fungi can accelerate the weathering process by producing organic acids, leading to a more rapid consumption of CO_2 by the applied basalt.

Why Bioenergy Crops?

Plant-based biofuels have been investigated and implemented as an alternative to fossil fuels for two reasons: they are renewable, and they sequester atmospheric carbon in the bioenergy crop plant tissues before conversion to fuel, reducing the effect of fuel combustion on atmospheric CO_2 concentrations compared to conventional gasoline and diesel. Because enhanced weathering seeks to minimize carbon dioxide release to the atmosphere, bioenergy crops offer the opportunity to "double down" by directly capturing CO_2 through enhanced weathering while reducing CO_2 release to the atmosphere by reducing fossil fuel consumption.

Bioenergy crops grown in the US include annual corn, canola, and soybeans, and perennial miscanthus, switchgrass, and fast-growing woody plants like willow and poplar.

Research Collaborators

The vision of the Institute for Sustainability, Energy, and Environment at the University of Illinois is to develop safe, productive, and sustainable solutions for the increasing food, water, and energy needs of Earth's growing population through actionable, interdisciplinary research.

The Leverhulme Centre for Climate Change Mitigation (LC3M) is directed by Dr. David Beerling FRS, at the University of Sheffield, Sheffield, UK. LC3M is a long-term research project funded by the Leverhulme Trust for the purpose of investigating enhanced weathering as a means of safely removing large amounts of CO2 from the atmosphere. The research incorporated four themes: earth systems modeling, fundamental science, applied science, and sustainability and society.

The Energy Farm was established through partnership between the University of Illinois and the Energy Biosciences Institute.

Publications

Lal R, 2004. Soil carbon sequestration to mitigate climate change. Geoderma 123, 1-22.

Moosdorf N, Renforth P, and Hartmann J, 2014. Carbon dioxide efficiency of terrestrial enhanced weathering. Environmental Science & Technology 48, 4809-4816.

Kantola IB, Masters MD, Beerling DJ, Long SP, and DeLucia, EH, 2017. Potential of global croplands and bioenergy crops for climate change mitigation through deployment for enhanced weathering. Biology Letters, in press.

Further Information

For more information on climate change, atmospheric carbon dioxide, and ocean acidification, see:

"Climate change: How do we know?" NASA Global Climate Change, climate.nasa.gov

"Effects of the Changing the Carbon Cycle," NASA Earth Observatory, earthobservatory.nasa.gov

"Ocean Acidification," NOAA Pacific Marine Environmental Laboratory Carbon Program, pmel.noaa.gov