

How can we store carbon dioxide from the atmosphere in minerals?



Authors:

Erika La Plante, Gaurav Sant, Dante Simonetti, and others

Associate Editors:

Allison Gamzon and Rachel Watson

Abstract

Did you know that the sea level is rising and that weather patterns are changing worldwide? Because of human activities, there is extra carbon dioxide in the atmosphere. That's why the Earth has gotten warmer. What can we do about it? We can take the carbon dioxide out of the atmosphere and store it. Current technologies transform it into a liquid and pump it back into the ground. Unfortunately, this way of doing things can be expensive and difficult to manage. That's why we created a different method of collecting

carbon dioxide from the atmosphere. Our process uses the natural ability of ocean water to absorb carbon dioxide from the atmosphere. Then it forms minerals that we can store or use. Our observations proved that our process successfully removes carbon dioxide from the atmosphere. Our analysis also showed that our method is more energy efficient and environmentally friendly than current technologies.

Introduction

As a greenhouse gas, carbon dioxide (CO_2) helps keep the Earth warm and comfortable for life to exist. How? It traps outgoing energy from the Earth, the same way a blanket traps your outgoing energy to keep you warm. The problem with CO_2 is that when there is a lot of it in the atmosphere, the Earth gets too warm. And when the Earth warms up, there are lots of changes to the ocean and weather patterns. These changes negatively affect ecosystems and human society. Our fossil fuel use and industrial processes emit about 37 **gigatonnes** of CO_2 per year. To prevent the Earth from warming too much, we must find a way to remove CO_2 from the atmosphere.

One option is **carbon capture, sequestration, and storage (CCSS)**. With most CCSS, the first step is to remove CO_2 from the atmosphere and pressurize it into a liquid. Then, we inject it into the ground. This process can store a large amount of carbon dioxide, but it uses a lot of energy to remove it from the atmosphere. Also, the liquid carbon dioxide might move and leak out into the environment. Exposure to high levels of carbon dioxide can cause significant health effects.

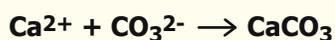
That's why we developed a different approach. Ocean water absorbs CO_2 from the atmosphere. **Chemical reactions in our technology cause it to form into carbonate minerals.** We call our new method **single-step carbon sequestration and storage (sCS²)**.



Calcite is one of the most common carbonate minerals.

Methods

We focused on the formation of calcite (CaCO_3) because it is an easy mineral to form from carbon dioxide. Ocean water contains many **ions**: calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}), and chloride (Cl^-). When the ocean absorbs carbon dioxide from the atmosphere, CO_2 reacts with the water to form carbonate ions (CO_3^{2-}). When the calcium ions in the water react with the carbonate ions, you get calcite.



To find the best conditions for making calcite, we tested different **pH** levels and measured the amount of calcite produced. The pH tells us if a substance is an **acid**, **base**, or neutral.

We can raise the pH of water samples by adding sodium hydroxide (NaOH), which is a strong base. Our sCS^2 device can do something very similar. In the device, seawater that contains **dissolved** CO_2 , passes through a mesh that causes water **electrolysis** (Fig. 1). In electrolysis, electricity is used to break water apart. This reaction makes hydroxide (OH^-) ions. These ions cause the pH to increase, making it easier for the carbonate ions and the calcium ions in the water to form calcite.

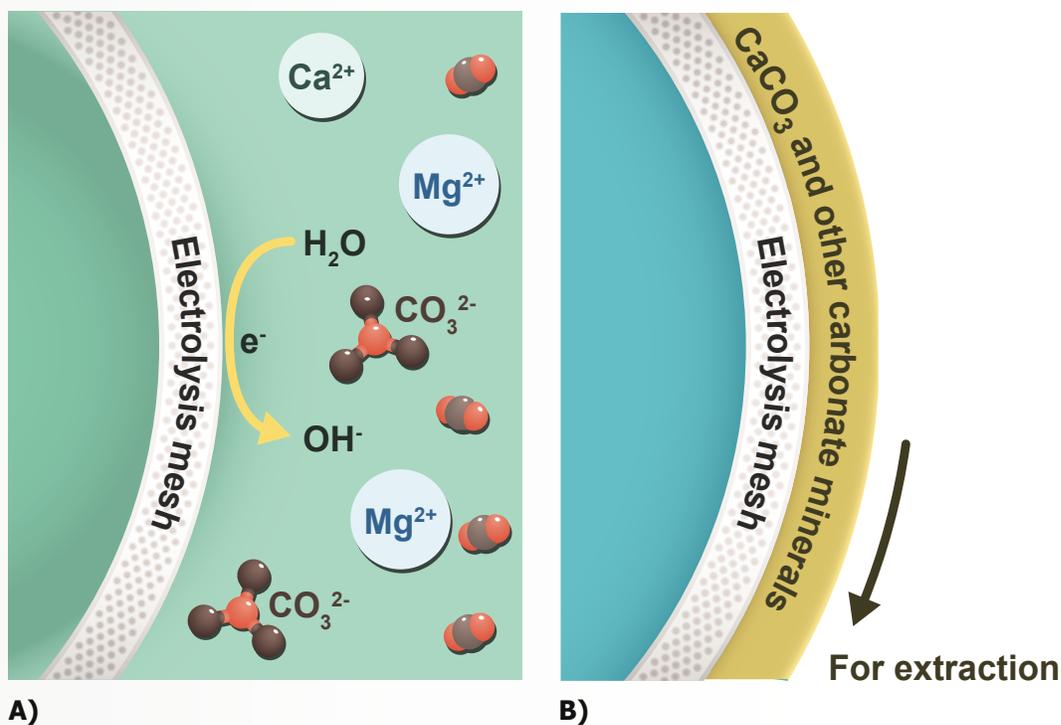
Figure 1:

An illustration of single-step carbon sequestration and storage (sCS^2).

A) The electrolysis mesh makes hydroxide ions from water.

B) Calcite (CaCO_3) and other carbonate minerals form when the calcium (Ca^{2+}) and magnesium ions (Mg^{2+}) react with carbonate ions (CO_3^{2-}) in the ocean water.

Where do the carbonate minerals form once the hydroxide ions are created by the mesh?



Results

Our sCS^2 process was successful at creating calcite from ocean water. Our experiment using sodium hydroxide confirmed that calcite forms faster when there is a high pH. In our sCS^2 device, the calcite minerals formed near the

electrolysis mesh. As the distance from the mesh increased, the amount of calcite formed decreased. We also noticed the formation of magnesium carbonate minerals near the

Discussion

Our research showed we can transform CO_2 from the atmosphere into carbonate minerals using ocean water. This process is more efficient than the traditional process. That's because it skips the capture step. By using the natural ability of the ocean to absorb CO_2 , we can use less energy to remove it from the atmosphere. The sCS^2 process does need energy, though. That is because we need electricity to create the hydroxide ions that keep the pH high. But using electrolysis is important because making sodium hydroxide uses a lot of resources.

Another advantage of sCS^2 is that the minerals it produces do not harm the environment. So we can decide: Should we discharge them into the ocean? Should we collect them and use them? We did some calculations based on the small

sCS^2 device we created. We estimate 10 gigatonnes of CO_2 will create 20 gigatonnes of carbonate minerals. These could be used in both construction and the production of materials such as concrete.

Because the minerals in sCS^2 formed close to the mesh, we had to remove them so that more minerals could form. We need more research to find a better way to keep the electrodes clean. That way the calcite production can be continuous. Our current idea is to add a rotating system that would scrape the minerals off the electrodes. Then we could collect the minerals and keep reusing the mesh.

Conclusion

Our sCS^2 method provides a new, quick way to remove carbon dioxide from the atmosphere. Until sCS^2 becomes available, we must continue to reduce the amount of CO_2 that enters the atmosphere. How can you help? Conserve energy whenever you can. Choose reusable items over

disposable ones whenever possible. And promote the use of renewable energy at home and in your community. By reducing the amount of CO_2 entering the atmosphere, we can help the Earth avoid getting too hot.

Glossary of Key Terms

Acid – a substance with a low pH that gives off hydrogen (H^+) ions in water. Examples include lemon juice, vinegar, and carbonated drinks like cola.

Base – a substance with a high pH that gives off hydroxide (OH^-) ions in water. Examples include soap, ammonia, and baking soda.

Carbon capture, sequestration, and storage (CCSS) – the process of removing carbon dioxide from the atmosphere, changing it, and then storing it.

Carbonate minerals – any mineral that contains the carbonate ion (CO_3^{2-}). Examples include calcite, dolomite, aragonite, and rhodochrosite.

Dissolve – to become incorporated into a liquid to form a solution. Solids and gasses can both dissolve in liquids. For example, salt can dissolve in water to make saltwater. Carbon dioxide can dissolve in water to make carbonated drinks.

Electrolysis – when a liquid is broken down by passing electricity through it.

Gigatonne – a unit of mass used to describe changes in the atmosphere. A ton is a unit of mass equal to 1,000 kilograms. 1 gigatonne is equal to 1 billion tons. That's the mass of 200 million elephants or 20,000 Titanic ships!

Ions – atoms or molecules that have a charge because they have lost or gained electrons. If electrons are lost, the ion has a positive charge. If electrons are gained, the ion has a negative charge.

pH – a scale used to determine the acidity of a substance. 7 on the pH scale is considered neutral. A substance with a pH below 7 is an acid. A substance with a pH above 7 is a base.

Single-step carbon sequestration and storage (sCS^2) – our new method for removing carbon dioxide from the atmosphere and changing it through water electrolysis into calcite.

Check your understanding

1 What does ocean water contain that helps produce carbonate minerals from carbon dioxide?

2 Why do the researchers consider sCS² more efficient than traditional carbon capture, sequestration, and storage techniques?

3 Sodium hydroxide was a base that was used to raise the pH so the calcite would form faster. What are other bases that you interact with in your everyday life?

4 We identified two options for the disposal of the minerals created by sCS². Create an argument for which option is the best. Then support your argument with evidence.

5 There are many ways you can help reduce the amount of carbon dioxide released into the atmosphere, including some suggested in the article. Select one and explain how this change would reduce CO₂ emissions. Then evaluate this suggestion. Would you be able to implement it? Do you think your friends and family would commit to it as well? Explain your answer fully.

REFERENCES

Erika Callagon La Plante, Dante Simonetti, Jingbo Wang, Abdulaziz Al-Turki, Xin Chen, David Jassby, and Guarav Sant (2021) *Saline Water-Based Mineralization Pathway for Gigatonne-Scale CO₂ Management*. ACS Sustainable Chemistry & Engineering.

<https://pubs.acs.org/doi/10.1021/acssuschemeng.0c08561>

CLEAR Center, UC Davis. What is Carbon Sequestration and How Does it Work?

<https://clear.ucdavis.edu/explainers/what-carbon-sequestration>

PBS Learning Media: Ionic Bonding

<https://cptv.pbslearningmedia.org/resource/lsp07.sci.phys.matter.ionicbonding/ionic-bonding/>