Carbon Dioxide Removal

An Elemental Adventure

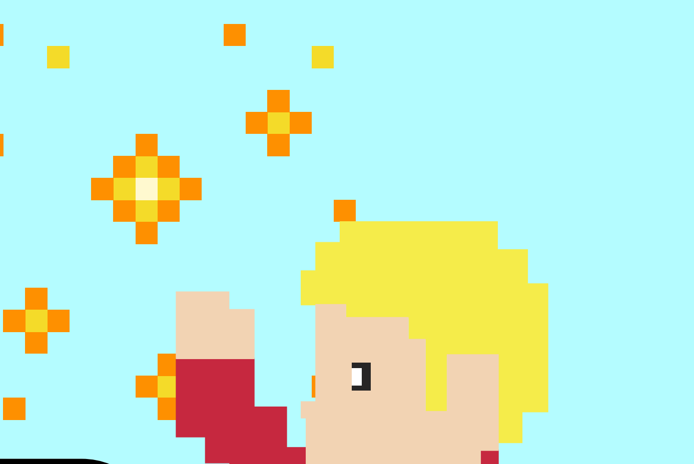
Your Mission

Man made processes such as burning fossil fuels for energy has been adding carbon dioxide and other greenhouse gases (GHGs) to the atmosphere! This is causing hotter temperatures, intensified weather, and more. **Your mission is to choose which methods we should use to remove carbon dioxide from the atmosphere.** Choose wisely; each method has its pros and cons.

Goals

- Net zero carbon dioxide emissions by 2050
- Transition to using clean energy
- Minimize environmental destruction

Save the Earth!



Helpful Tips

- Carbon capture is not the same thing as carbon dioxide removal!
- **Carbon capture** stops the addition of carbon
- **Carbon removal** pulls existing carbon out of the atmosphere

Equip Yourself!

There are multitudes of carbon removal technologies in research, development, and deployment. Education, government support, and financial incentives are all needed for every method to be brought to large-scale adoption.

Air

Direct Air Capture (DAC)

- Captures carbon dioxide from the air using a chemical substance
- DAC plants can be located anywhere that has low-carbon energy which is useful for large-scale adoption
- More research on DAC in varying climate conditions is needed
- Currently, 18 plants worldwide capture 10,000 tons per year [1]

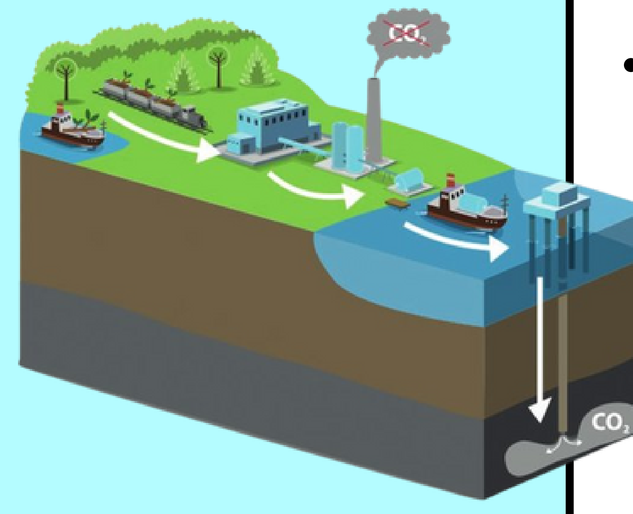
DAC with Aqueous Amino Acids

- Uses amino acids like potassium glycinate to absorb carbon dioxide
- Amino acids can be regenerated and used multiple times for carbon removal
- Amino acids have fast reaction rates and low toxicities which enhances carbon removal capacity [2]
- This is one of the newest methods and still in the research stage

Fire

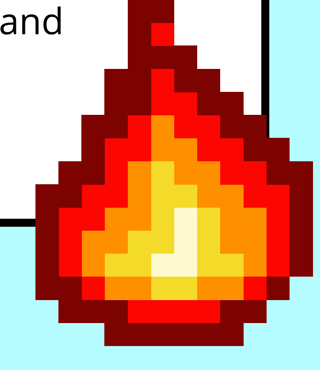
Bioenergy with Carbon Capture and Storage (BECCS)

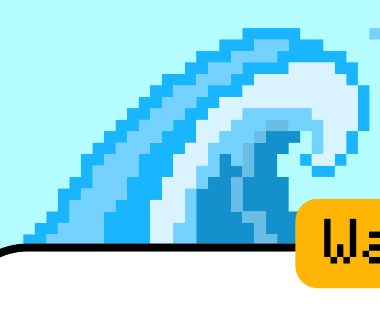
- Focuses on growing and burning biomass to produce fuel and store carbon emissions
- Already one of the most popular methods and has been used in 3 out of 4 of Intergovernmental Panel on Climate Change (IPCC) models [3]
  Could potentially displace rural communities and decrease biodiversity due to the increase need of land for growing biomass



Biochar

- Burns biomass through pyrolysis, the degradation of materials in the absence of oxygen
- This produces little to no fumes along with energy that can be used as clean energy
- The product of pyrolysis is a charcoal-like material that stores carbon but can also be used to help improve soil quality [4]
- Causes a risk of contamination and possible loss of land





Water

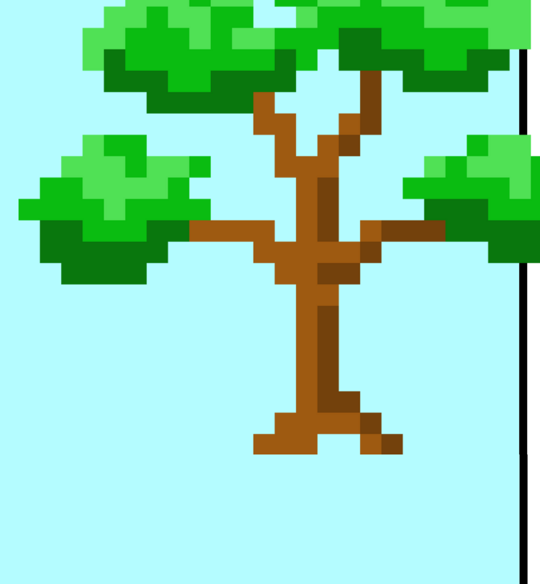
Planetary Technologies

- Planetary Technologies is a new company from Canada focusing on decreasing the acidity of the ocean by adding antacid to seawater to turn acidic carbon dioxide in the water into bicarbonate [5]
- If the ocean is less acidic then it will want to absorb additional carbon dioxide from the air to keep the total concentration balanced
- The technology is still brand new and only recently got permitted to start open-ocean trials this year

Earth

Soil Carbon Sequestration

- Soil naturally absorbs and captures carbon dioxide, so this method focuses on managing land to better absorb and hold more carbon [6]
- Examples include no-till practices (not disturbing the soil), planting crops that don't need to be replanted every year, managing the grazing of livestock, and applying compost to fields
- This method also helps farmers increase yield and economic productivity
- However, once the soil is completely saturated with carbon it will be useless and might even release carbon if disturbed

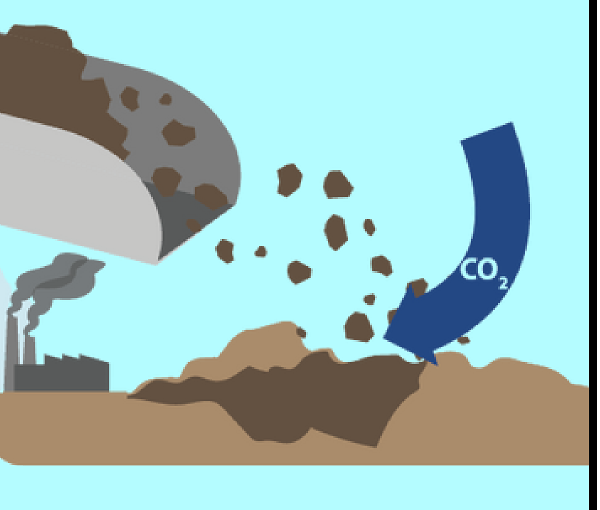


Biomass Carbon Removal and Storage (BiCRS)

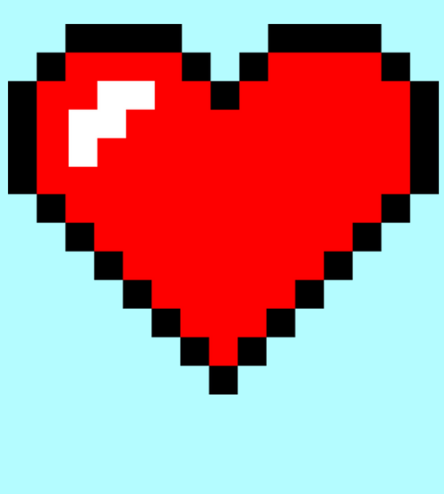
- Uses a similar methodology to BECCS but prioritizes carbon removal whereas BECCS emphasizes energy production first
- Focuses on promoting food security, rural communities, and biodiversity through the sustainable production of biomass like waste, carbon-removal crops, microalgae, and seaweed [7]
- This method was only coined recently so more research is needed to see the potential carbon removal data

Enhanced Mineralization

- Involves mining rocks such as basalt that have the ability to absorb and store carbon in the long term
- Weathering naturally converts around one billion tons of carbon dioxide into minerals every year, so this method speeds the process up [8]
- Can use waste materials that are already generated from the mining industry
- Creates risk of leaching from mining raw materials which causes both environmental and human health risks



Ready to reduce carbon? While you wait for your tools to equip, why not try eating less red meat, making your home more energy efficient, and reducing air travel?



START GAME ▶

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Carbon Dioxide Removal: Reducing our Footprint

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I. Why is carbon dioxide removal needed?

Carbon dioxide removal is a natural process in the carbon cycle, one of many important biogeochemical cycles that allow for life on Earth to survive and thrive. Historically, we have relied on the land and ocean to absorb carbon. More recently, the burning of fossil fuels for energy along with other man made technologies have begun to release more carbon dioxide than the natural processes can take. The excess carbon dioxide along with other pollutants has caused increasing temperatures, melting of sea ice, ocean acidification, weather intensification, and more, all together known as climate change. Carbon dioxide removal technologies are now needed in addition to the natural processes to allow for a sustainable Earth that future generations can enjoy. Countries from around the world have pledged to achieve net zero emissions (completely negating any greenhouse gas emissions produced by humans) by 2050, and carbon dioxide removal technologies will be needed to meet this goal.

II. Carbon dioxide removal versus point source carbon capture

There are many solutions to help clean up excess carbon dioxide in the environment. The two main methods are carbon dioxide removal and carbon capture. Carbon capture can stop carbon dioxide emissions produced by power plants therefore stopping the addition of new carbon emissions, but this method has no effect on carbon dioxide that's already in the atmosphere. It takes carbon dioxide from a point source and can lower or zero out the source's carbon footprint. On the other hand, carbon dioxide removal can create a negative footprint, targeting legacy emissions by removing carbon dioxide currently in the atmosphere. In this way, carbon dioxide is pulled out of the air and ultimately has a greater impact on the reduction of excess carbon dioxide.

III. Direct Air Capture (DAC)

Direct air capture is a type of carbon dioxide removal method that pulls carbon dioxide out of the air and stores it in geological formations. The captured carbon is then stored long term, or permanently. DAC has a limited land and water footprint and the captured carbon can even be used for food processing or in the production of synthetic fuels. Within DAC, there are two approaches: solid and liquid DAC. Solid DAC uses solid substances at low pressures and medium temperatures to absorb carbon dioxide, while liquid DAC uses an aqueous basic solution like potassium hydroxide. In theory, a DAC plant can be located anywhere that has low-carbon energy but further testing is needed in different climates to see the success of the operation. Support for DAC is growing, especially in the European Union which has commissioned support through the Innovation Fund which has a budget of $11.8 billion USD. Other countries are also showing support, such as the United States which established the 45Q tax credit to provide $50 per ton of carbon dioxide stored. The Investment and Jobs Act which was signed in 2021 also includes funding to build four DAC hubs and related infrastructure. Currently, there are only 18 direct air capture plants worldwide. The plants capture almost 10,000 tons of carbon dioxide per year, but the goal of net zero emission by 2050 would require DAC to capture 60,000,000 tons per year.

IV. Soil Carbon Sequestration

Soil carbon sequestration is a method of carbon dioxide removal that focuses on managing land to absorb and hold more carbon. There are various ways to manage this, such as switching to no-till practices (not disturbing the soil), planting perennial crops (crops that don't need to be replanted every year), managing the grazing of livestock, and applying compost and residue to fields. In addition to the capture and storage of carbon dioxide in the soil, these methods can also help farmers increase their yield and economic productivity. However, there are some drawbacks of the soil carbon sequestration method. First of all, soil is a finite capturing source. Once the land is saturated with carbon, the soil will no longer be able to hold any more carbon and may even release the carbon that was once captured if the soil were to be disturbed. It is also difficult to measure and verify the amount of carbon captured in this method. Currently, many farmers employ some or all of these methods but in order to meet the net zero emissions goal by 2050, these methods would need to be substantially scaled up. With financial incentives from the government, increased research on improving soil health, and improved monitoring standards, soil carbon sequestration can surely help with the removal and storage of carbon.

V. Biomass carbon removal and storage (BiCRS)

BiCRS is a relatively new method defined as a process that uses biomass to remove carbon dioxide and then stores the captured carbon underground or in long-lived products. BiCRS is more of a hybrid approach focusing specifically on using plants and algae to help reach the net zero emissions goal. Ideally, BiCRS promotes food security, rural communities, and biodiversity as compared to other carbon dioxide removal methods that critics say compete with food security and the other values. One analysis of the BiCRS method found that the process could potentially capture and store up to 5 gigatons of carbon dioxide annually by 2050. Ideally, the method would start with the sustainable production of biomass such as waste, carbon-removal crops, microalgae, and seaweed. The production of these sources would also help facilitate local economies. Then, the biomass would be shipped to BiCRS facilities, hopefully co-locating the facilities near the source in order to get transportation emissions as close to zero as possible. The carbon in the biomass would then be thermochemically converted and used in products like fuel or pumped underground into geologic storage. The implementation of BiCRS would require governmental incentives as well as international standards for biomass production. Interestingly, the BiCRS method prioritizes social situations much more than any other carbon removal method, citing a need for cooperation between countries (especially in giving recognition to the correct country when biomass is grown in one place but stored in another) as well as the importance of mindfulness of the impact on rural communities that other methods may have.

VI. Enhanced mineralization

Enhanced mineralization is a method for carbon removal that involves mining rocks like basalt that can absorb and store carbon for the long term. Naturally, weathering converts about one billion tons of carbon dioxide from the atmosphere into minerals every year. So, enhanced mineralization speeds this process up and can even use waste materials from the mining industry to do so. One way to enhance this process is grinding basalt and similar rocks into a powder to be spread over soils in order to form stable carbonate minerals for carbon removal. This can improve soil quality and be combined with other methods such as soil carbon sequestration. However, the increased amount of mining may cause other environmental concerns due to the processing of raw materials which can release other pollutants and may actually contaminate the soil or groundwater. For this method, it is important to consider not only environmental risks but health risks to humans as well. The extensive use of mining in this method could create concerns over viable drinking water sources, so increased monitoring by the government as well as policies to make sure both the environment and humans stay healthy are needed if this method is to be used to meet the net zero emissions goal by 2050.

VII. Bioenergy with carbon capture and storage (BECCS)

Bioenergy with carbon capture and storage is a method for capturing carbon dioxide from biomass. In simple terms, BECCS is a method to grow more biomass in a sustainable way which then naturally absorbs carbon dioxide from the atmosphere. The method depends on biomass being converted into heat or fuel, then storing the carbon emissions from the conversion in geological formations. This is a popular and viable method, and has been used in 3 out of 4 models that the Intergovernmental Panel on Climate Change (IPCC) made for reaching the net zero emissions goal. For BECCS, it is important to weigh the concerns of displacement and biodiversity which could be threatened by the land conversion for growing more biomass. The combustion of biomass during this process also raises concerns about local air pollution. In comparison to the biomass carbon removal and storage method (BiCRS), BECCS emphasizes energy production over carbon removal whereas BiCRS emphasizes the reverse. Therefore, smaller scale BECCS facilities may be more useful compared to large-scale adoption of BECCS which would compete with food security and biodiversity. More research on the sustainable production of biomass as well as research on the life cycle of BECCS operations is needed to consider using BECCS as a main method for reaching the net zero emissions goal.

VIII. Biochar

Biochar is a method for carbon removal in which biomass is burned during pyrolysis to create a substance that looks like common charcoal but that can convert and store carbon. During pyrolysis, little to no fumes are released since there is very little oxygen during the process. The energy created during pyrolysis can also be used as clean energy, and biochar itself can be used to help improve soil quality in degraded soils as well as be used in composting. By converting unstable carbon from the biomass into the stable form of carbon stored as biochar, this method definitely can contribute to the net zero emissions goal. Even though this method is considered novel just like all the other carbon removal methods, indigenous people in the Amazon used similar methods 2,000 years ago to create fertile soils. Today, areas of the Amazon that utilized ancient pyrolysis techniques continue to hold the carbon, confirming that biochar can be a long term solution. However, similar to other methods, some of the concerns with biochar include the loss of land and the risk of contamination. Therefore, further research is needed to implement the biochar method on a larger scale.

IX. Novel technology: DAC with aqueous amino acids

While certain methods may be more known to the public and scientific community, there are a multitude of new methods for carbon removal being researched and developed every day. One of these methods is the use of aqueous amino acids such as potassium glycinate and solid bisiminoguanidines (BIGs) to absorb carbon dioxide without the need to use energy to heat or burn any materials. The amino acids can even be regenerated and used again for carbon removal. This method solves one of the main problems with standard Direct Air Capture, which is that it is energy intensive and requires lots of heat to remove carbon from the atmosphere. Using amino acids in carbon removal is a novel approach, but can significantly enhance the carbon removal capacity and absorption rates due to their fast reaction rates and low toxicities. Overall, this method is still in the research stage and more funding and support is needed to determine it’s large-scale viability.

X. Novel technology: Planetary Technologies

Planetary Technologies is a Canadian company that focuses on decreasing the acidity of the ocean. Their methodology is that the concentration of carbon dioxide in the atmosphere and carbon dioxide in the ocean is always in balance, so if the ocean is less acidic due to less carbon dioxide, the ocean will want to absorb additional carbon dioxide from the air. Planetary Technologies is working to do this by adding antacid to seawater, turning acidic carbon dioxide into bicarbonate that stays in the water for years. The technology is still in development as the company is only starting open-ocean trials this year. Government policies and permits will be required for this novel carbon removal approach.

XI. Looking to the future

Carbon dioxide removal is not as widely used as or known about as compared to point source carbon capture. This is due to the limited research on removal versus capture, and also because removing carbon dioxide from the air is more energy intensive and expensive than capturing carbon at the source. In order to increase the deployment of carbon dioxide removal technologies, increased support should be aimed towards the research and development of CDR technologies. New grants and government policies can also help decrease the barriers to development. Lastly, education to the general public about implementing CDR technologies can help.

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