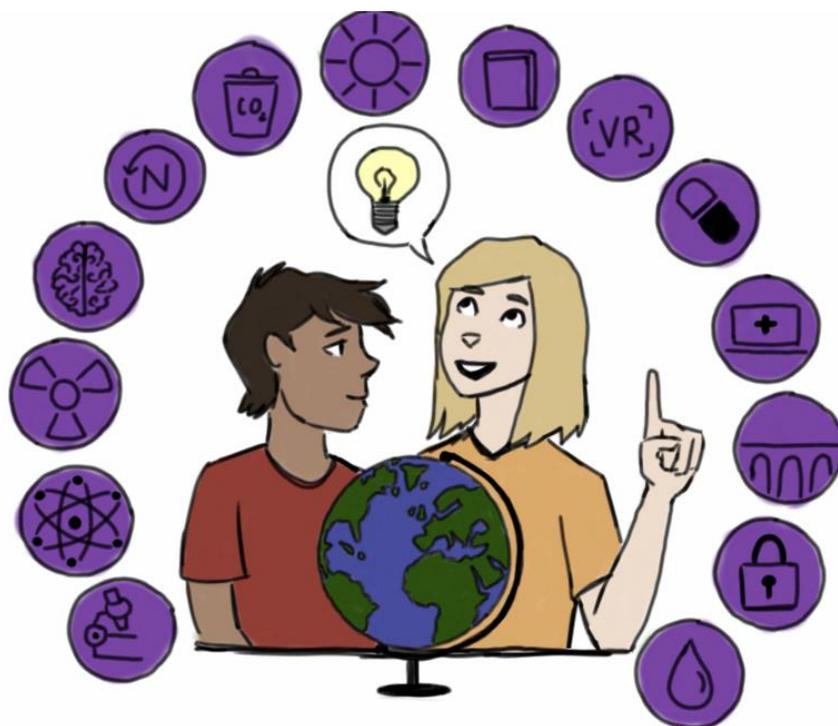


Organic Solutions



Grand Challenge: Carbon Sequestration

Tyler Askren

James Beil

Kaelyn Griffin

Aaron Jones

Kirby Kern

Learning Objectives

Global warming is one of the most significant issues currently impacting the world, and this module is designed to introduce students to a possible part of the solution to this issue - carbon sequestration, a promising yet relatively novel and underdeveloped technology and one of the least well known of the grand challenges of engineering. It also is designed to give students a hands-on opportunity to work through the engineering design process. This module is a fun way for the students to develop solutions to engineering problems firsthand.

Technical Background

Carbon sequestration is the process of collecting carbon, most often carbon dioxide, and storing it. Several methods of capturing carbon dioxide are currently being researched. One of these methods involves farmers retaining additional carbon in their soil by tending to it differently [1]. Research is also being conducted into methods of collecting carbon dioxide directly from the air, directly decreasing the amount in our atmosphere and slowing global warming [2]. Both of these processes are promising, but the process our team found most intriguing involves the removal (or “scrubbing”) of carbon dioxide from the flue gas emitted by power plants and factories. This method of carbon dioxide management has already been employed by several fossil fuel-burning power plants and other projects [3].

Flue gas is a generic term for any waste gas that leaves a plant and is released into the atmosphere. Despite a number of EPA regulations [4] that require the removal of certain chemicals from flue gas, a significant amount of carbon dioxide is still being emitted into the atmosphere by these facilities. Removing additional carbon dioxide from this flue gas reduces the gas’s contribution to the greenhouse effect. A scrubber system accomplishes this using a liquid solvent [5]. The liquid is sprayed into the gas, and the carbon dioxide dissolves into the liquid. This liquid is later reheated, chemically dissociating the mixture and producing a compressed stream of pure carbon dioxide to be sent to storage sites.

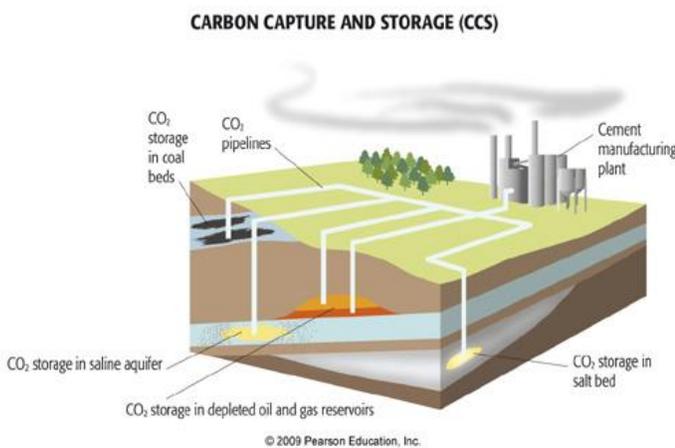


Figure 1: A diagram illustrating different methods of storing carbon dioxide in the ground. [7]

Once collected, the carbon dioxide can be stored in a number of ways. It can be used in enhanced oil recovery, in which it is injected into the ground and used to displace oil, allowing more oil to be obtained from depleted reservoirs [6]. The carbon dioxide gas then remains in the depleted oil reservoir. It can also be stored in various geological formations, as shown in the diagram in Figure 1 [7]. Our team has decided to focus on storing the carbon dioxide in porous rock formations and salt beds, where it eventually solidifies and turns into chalk [8]. Our module aims to teach the students about this particular form of carbon storage.

Materials and Budget

The following bill of materials lists the worst case cost, as many of our supplies are common classroom supplies that teachers are likely to already have in their classrooms. The second bill of materials lists a more realistic cost, as it does not factor in the cost of items that most teachers already have. Both budgets assume eight groups of three students. Having a smaller number of groups reduces the cost. Many different materials can be used to make interesting filter designs, so educators are encouraged to provide any additional materials they have access to.

The clear vinyl tubing can easily be found at any hardware store for \$.50 per foot.

Worst Case Budget		
Item	Qty	Cost
Paper Towel Tubes	pack of 8	\$20.00
Cardstock Paper	1 package	\$5.00
Handheld Single Hole Punches	8	\$40.00
Scotch tape	8 rolls	\$6.00
Safety scissors	8	\$20.00
M&Ms (plain)	At least 20 oz	\$4.00
Nerds candy	At least 20 oz	\$6.00
Clear Vinyl (0.5") Tubing	5 feet	\$2.50
Assorted cereal	Four different boxes	\$12.00
Small Baking Funnels	8	\$32.00
Tupperware, at least 3" deep	8	\$20.00
Small paper cups	1 package	\$3.00
Stopwatches	1	\$5.00
Total \$		\$175.50

Realistic Budget		
M&Ms (plain)	At least 20 oz	\$4.00
Nerds candy	At least 20 oz	\$6.00
Clear Vinyl (0.5") Tubing	5 feet	\$2.50
Assorted Cereal	4	\$12.00
Small Baking Funnel	8	\$32.00
Tupperware, at least 3" deep	8	\$20.00
Total \$		\$76.50

Approximate Schedule	
Introduction to Carbon Sequestration	3 Min
First set of directions	1 Min
Pre-Activity Questions	5 Min
Building Stage	10 Min
Pre-Filter Questions	2 Min
Test Filters	5 Min
Second Set of Directions	1 Min
Pick Cereal and Deposit Nerds	5 Min
Post-Activity Questions	3 Min
Total Time	35 Min

Module Procedure

Our team employed the following method of presenting the module to the students. It was very successful at facilitating the module and engaging the students, and we recommend this method.

Pre-Activity Setup

Mix together Nerds and M&Ms in paper cups, one for each team. Each team should have approximately the same amount of the mixture. This candy mixture represents the gas mixture emitted by power plants and factories, with the Nerds representing the carbon dioxide and the M&Ms representing all of the other flue gases. We found that giving each team thirty M&Ms and a similar volume of Nerds worked well. Collect paper towel tubes, cardstock paper, hole punches, safety scissors, scotch tape, and empty paper cups, and lay them out for each team. The students will design and build their simulated CO₂ scrubbers with these tools. You will also need one piece of Tupperware, a funnel, and some vinyl tubing for each group as well as a variety of cereals, however, you will not need to use these until the second part of the module. Print out a handout (Appendix A) for each student and distribute them before beginning the module.

Explanation to Students

Begin the demonstration by making sure that the students understand global warming, why it is an important problem, and how carbon dioxide relates to it. Present carbon sequestration as a potential piece of the solution to global warming, describing how it works, from carbon scrubbing to transportation to storage in a porous rock formation (as explained in the “technical background” section).

Next, explain to the students what they are about to do during the design phase of the module, and how it relates back to the process of carbon sequestration.

First, the students will design a filter to separate out the Nerds (CO₂) from the M&Ms (other flue gases). This system will have to filter out the Nerds from the candy mixture that you have made. The students will eventually pour their candy from the first cup through their filter into another cup. They will compete with the other teams to build the best filter. Their filters will be scored based on the criteria of filtering speed, how many Nerds they leave behind in their filter, how many M&Ms they let through the filter, and how much candy they spill. They can shake their filter as much as they want to during the filtering process, but should not directly touch the candy. They will blueprint their system on the provided handout prior to building anything. Within their groups, the students should discuss how to best use the materials, problems they could encounter, and potential improvements to their designs. They can test out their designs and iterate on them as much as they would like within the time allotted for design. As they work through this design phase, they should complete the pre-activity questions on the worksheet.

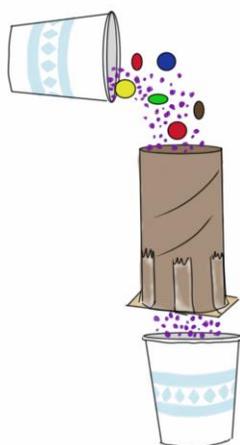


Figure 2: Part one of the demonstration - pouring candy through a filter

At this point, the scoring system should also be explained to the students:

- Each team begins with 300 points.
- You lose 1 point per second that you spend filtering out Nerds.
- You lose 1 point per Nerd left behind in the filter.
- You lose 5 points per M&M that makes it through your filter into the cup of Nerds.
- You lose 1 point per piece of candy (Nerds or M&Ms) that falls onto the table/floor.
- Whoever has the most points at the end wins!

Next, the students will fill out the pre-test questions, in which they will predict whose filter they think will perform the best and why. At this point, the students will test out their filters. Each team should be timed while they filter the candy mixture. They will pour the candy mixture into the filter over the empty cup. They can choose to stop filtering whenever they want, at which point the timer will be stopped (it may be advantageous to stop early if their rate of filtering is less than one Nerd per second).

To prepare for the next part of the activity, explain to the students that what they will be doing simulates the storage of the carbon dioxide in the earth. Let the students choose which type of cereal they think will be best for depositing the Nerds. Pour their cereal of choice into the Tupperware so that the container is about halfway full. Let the students bore their tube into the cereal and then pour their Nerds through the tube using the funnel. They should encounter some difficulties like clogs and jams. Let them work through this however they like, being sure to draw parallels to the difficulties of storing CO₂ in a porous rock formation. After they pour out their Nerds, let them look at the container from the top and the bottom to decide how well their Nerds are buried. Relate this to how storing the carbon dioxide deep into the ground does not allow it to be released back into the atmosphere.

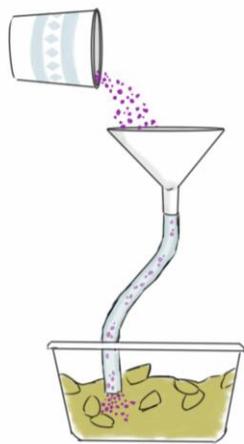


Figure 3: Part two of the demonstration - transporting Nerds into cereal

Goals of this Module

By the end of this module, the students will be familiar with the process of carbon sequestration, and they will have experienced the engineering design process in an entertaining and engaging way. This module provides students with a hands-on learning opportunity, and is a helpful way to reinforce the lessons that they have learned in the classroom. Through this module, we hope to foster an interest in STEM, and we hope to encourage them to pursue careers in STEM-related fields. The world needs more individuals in STEM careers to develop innovative solutions to urgent problems like climate change, and we hope to play a role in inspiring students to develop these solutions.

Supplementary Sources

Additional information about carbon sequestration and other grand challenges:
<http://www.engineeringchallenges.org/>

FAQ's

What is Flue gas?
<http://www.merriam-webster.com/dictionary/flue%20gas>

How is CO₂ removed from flue gas?
https://www.youtube.com/watch?v=adu4-ahLE_0

What is the greenhouse gas effect?
<http://ossfoundation.us/projects/environment/global-warming/greenhouse-gases>

What is the EPA doing about CO₂ emissions?
<http://www3.epa.gov/climatechange/EPAactivities/regulatory-initiatives.html>

Sources

[1] W. M. Post, R. C. Izaurralde, J. D. Jastrow, B. A. Mccarl, J. E. Amonette, V. L. Bailey, P. M. Jardine, T. O. West, and J. Zhou, "Enhancement of Carbon Sequestration in US Soils," *BioScience*, vol. 54, no. 10, p. 895, 2004. [Accessed: 13-Jan-2016].

[2] E. Kintisch, "Can Sucking CO₂ Out of the Atmosphere Really Work?," *MIT Technology Review*, 07-Oct-2014. [Online]. Available at: <http://www.technologyreview.com/featuredstory/531346/can-sucking-co2-out-of-the-atmosphere-really-work/>. [Accessed: 13-Jan-2016].

[3] "Carbon Capture and Sequestration Project Database," *Carbon Capture and Sequestration Technologies @ MIT*. [Online]. Available at: <http://sequestration.mit.edu/tools/projects/index.html>. [Accessed: 6-Feb-2016].

[4] "Cleaner Power Plants," *Cleaner Power Plants*. [Online]. Available at: <http://www3.epa.gov/mats/powerplants.html>. [Accessed: 13-Jan-2016].

[5] "Solvent Capture," *Solvent Capture*. [Online]. Available at: <http://www3.imperial.ac.uk/carboncaptureandstorage/carboncapture/solventcapture>. [Accessed: 13-Jan-2016].

[6] S. I. Plasynski and D. Damiani, "Carbon Sequestration Through Enhanced Oil Recovery," *Carbon Sequestration through Enhanced Oil Recovery*, Apr-2008. [Online]. Available at: <http://www.netl.doe.gov/publications/factsheets/program/prog053.pdf>. [Accessed: 13-Jan-2016].

[7] "PennState - From Meteorology to Mitigation: Understanding Global Warming," *Google Images*. [Online]. Available at: https://www.google.com/imgres?imgurl=https://www.e-education.psu.edu/drupal6/files/meteo469/lesson11/ccs_dp.jpg. [Accessed: 13-Jan-2016].

[8] "Carbon Sequestration Cereal Demo," *YouTube*, 13-Oct-2008. [Online]. Available at: http://www.youtube.com/watch?v=vngkttape_q. [Accessed: 13-Jan-2016].

Appendix A

Team Name _____

Directions

- Design a way to filter the Nerds out from the M&Ms
- Use the filter to separate the M&Ms from the Nerds

Pre-Activity Questions

1) Sketch the design that you plan to build:

2) What materials did you choose for your filtration device? Why did you choose these materials?

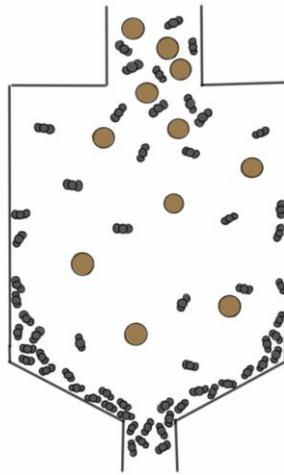


Figure 1: This drawing is a simplified representation of carbon dioxide scrubbing. The smaller, grey molecules are the carbon dioxide molecules and the larger brown molecules are the other flue gases.



Figure 2: The carbon dioxide is transported down a pipeline and stored in a geological formation. The liquid carbon dioxide fills in the gaps in the porous rocks and over time will turn into chalk, a stable form of carbon dioxide.

Before Testing the Filter

1) Looking at the other groups' filter, whose design do you think will work the best? Why?

Points

Start with: 300 Points

Time Taken: -1 Point per Second

Candy Dropped: -1 Point per Candy Dropped

M&Ms Let Through: -5 Points per M&M

Nerds Left Behind: -1 Point per Nerd

Team Name	Time (seconds)	Nerds Left Behind	M&Ms Let Through	Candy Dropped	Points

Directions

- Select a cereal in which to store your Nerds
- Transport the Nerds to the cereal

Post-Activity Questions

1) What do the Nerds represent?

2) What do the M&Ms represent?

3) What does the cereal represent?

4) Were there any changes you would make to your design? Did any part of your original design not work? How did you fix it?

5) How easy was it for you to pour your Nerds into your cereal? Would you pick a different cereal now?