

**Teacher’s Guide**

**Capturing Carbon**

***April 2020***

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Activate students’ prior knowledge and engage them before they read the article.

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These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You’ll find the questions ordered in increasing difficulty.

[Graphic Organizer 5](#_Graphic_Organizer)

Thishelps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.

[Answers 6](#_Answers_to_Reading)

Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.

[Additional Resources 9](#_Additional_Resources_1)

Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article.

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# Anticipation Guide

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The challenge we have in capturing greenhouse gases is to scale them quickly. |
|  |  | 1. By weight, CO2 accounts for most of the greenhouse gases released into the atmosphere annually. |
|  |  | 1. Technologies to remove CO2 from the atmosphere can eliminate the need for other measures to reduce greenhouse gas emissions. |
|  |  | 1. When CO2 is captured from the air, it is trapped on a sorbent where it can be released later as a raw material for new products. |
|  |  | 1. Bioenergy systems capture CO2 in plants and other agricultural products, then burn the biomass to produce electricity and heat. |
|  |  | 1. Carbonate-containing minerals are toxic. |
|  |  | 1. Carbon dioxide can be injected underground as a solid. |
|  |  | 1. Coastal wetlands hold vast amounts of carbon in their soils and plants. |
|  |  | 1. The first Earth Day was held more than 60 years ago. |
|  |  | 1. A shift toward a plant-based diet could significantly reduce greenhouse gases in the agricultural sector. |

# Student Reading Comprehension Questions

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: Use the article to answer the questions below.

1. What are NETs and how do they reduce the carbon dioxide in the atmosphere?
2. The UN Environment Program recommends that we reach net zero emissions by 2050. What is the difference between “zero emissions” and “net zero emissions”?
3. You have likely heard of the terms *carbon footprint* and *carbon emissions*. The title of this article is *Capturing* *Carbon*. Carbon is a general term used by scientists and the general population to discuss some of the gases in the atmosphere that have effects on climate change.
   1. What are some more specific names of these gases in the atmosphere?
   2. Why can the word carbon be used as a generalization for these chemicals?
4. Extraction of CO2 from air requires the use of a sorbent.
   1. What is the difference between absorption and adsorption?
   2. Why would a low-temperature desorption method be an improvement to the air extraction technology design?
5. What must be true of a bioenergy technology to claim that it “captures carbon twice”?
6. Earth does a pretty good job of making rocks and minerals. Humans are experimenting with the idea of reacting CO2 from the air with certain metal oxides naturally found in the earth to create similar kinds of minerals, thus capturing CO2.
   1. Write the balanced chemical equations that show this process for each of the main metal oxides found in basalt rock. (The equation for the reaction with CaO is given in the article.)
   2. Why is this process classified as negative emissions?

**Student Reading Comprehension Questions, cont.**

1. How does planting trees address the goal of capturing carbon?

*Study the graph showing the phase diagram on page 14 and answer the remaining questions.*

1. If normal atmospheric conditions are about 25 oC and 1 atm, what is the state of matter in which CO2 exists in our atmosphere?
2. What conditions must be applied to CO2 so it becomes a supercritical fluid?
3. Considering the goal of NETs, why would you want to avoid applying heat to CO2 to assist in this transition to supercritical fluid?

**Questions for Further Learning**

***Write your answers on another piece of paper if needed.***

1. Choose one NET. Identify the advantages and disadvantages of using this technology. Then explain how scientists and engineers should weigh the pros and cons to decide whether this technology should be used on a large scale.
2. The graphic on page 12 contains a quote that says: “We have technologies to remove greenhouse gases from air, but it’s less clear whether we can scale them fast enough to make a difference.”
   1. What does it mean to scale these technologies?
   2. Why would it be difficult to scale the technologies?
3. You may have seen advertisements for the Impossible Burger, which is described as the meatless burger or meat made from plants. This company’s mission begins with the goal, “To drastically reduce humanity’s destructive impact on the global environment by completely replacing the use of animals as a food production technology.” How does meat production increase our carbon footprint?

# Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: As you read, complete the graphic organizer below to describe each type of carbon capture described in the article.

|  |  |  |
| --- | --- | --- |
| **NET** | **How it works** | **Possible Problems** |
| **Extracting from Air** |  |  |
| **Burning New Fuels** |  |  |
| **Making Rocks** |  |  |
| **Burying Underground** |  |  |
| **Growing Plants** |  |  |

**Summary:** On the back of this paper, write a tweet (280 characters or less) describing one of the technologies to remove carbon from the atmosphere.

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **What are NETs and how do they reduce the carbon dioxide in the atmosphere?**

*Negative Emission Technologies. They are technologies that take CO2 out of the atmosphere in a variety of ways. They are called negative emission because they are attempting to take away the emitted molecules, thus subtracting them from total emissions.*

1. **The UN Environment Program recommends that we reach net zero emissions by 2050. What is the difference between “zero emissions” and “net zero emissions”?**

*Zero emissions means that we are not allowing any greenhouse gases into the atmosphere from our various human endeavors. Net zero emissions means that we will take out as much greenhouse gas from our atmosphere as we have put in, making the sum total of emissions zero.*

1. **You have likely heard of the terms carbon footprint and carbon emissions. The title of this article is *Capturing Carbon*. Carbon is a general term used by scientists and the general population to discuss some of the gases in the atmosphere that have effects on climate change.** 
   1. **What are some more specific names of these gases in the atmosphere?**

*Carbon dioxide (CO2) and methane (CH4)*

* 1. **Why can the word carbon be used as a generalization for these chemicals?**

*They are both carbon-containing compounds that have an impact on energy transfer in our atmosphere.*

1. **Extraction of CO2 from air requires the use of a sorbent.**
   1. **What is the difference between absorption and adsorption?**

*Absorption is when a substance mixes into another substance. Adsorption is when a substance adheres to another substance, either on the surface or in pores.*

* 1. **Why would a low-temperature desorption method be an improvement to the air extraction technology design?**

*Using a high temperature would require energy, which would use some kind of technology that generates emissions, thus lowering the impact of the negative emission technology.*

1. **What must be true of a bioenergy technology to claim that it “captures carbon twice”?**

*Its first capture is when it is growing. It is capturing carbon dioxide through photosynthesis. If the biomass is used for burning, then its emissions must be captured in order for the technology to capture the carbon dioxide a second time.*

1. **Earth does a pretty good job of making rocks and minerals. Humans are experimenting with the idea of reacting CO2 from the air with certain metal oxides naturally found in the earth to create similar kinds of minerals, thus capturing CO2.**
   1. **Write the balanced chemical equations that show this process for each of the main metal oxides found in basalt rock. (The equation for the reaction with CaO is given in the article.)**

*MgO(s) + CO2(g) 🡪 MgCO3(s)*

*CaO(s) + CO2(g) 🡪 CaCO3(s)*

*FeO(s) + CO2(g) 🡪 FeCO3(s)*

* 1. **Why is this process classified as negative emissions?**

*It is taking carbon dioxide from the air and storing it in the earth. This process does not require an input of energy, so it is only reducing emissions that were already present.*

1. **How does planting trees address the goal of capturing carbon?**

*Increasing the number of plants growing on earth increases the amount of CO2 taken out of the atmosphere due to photosynthesis.*

**Study the graph showing the phase diagram on page 14 and answer the remaining questions.**

1. **If normal atmospheric conditions are about 25 oC and 1 atm, what is the state of matter in which CO2 exists in our atmosphere?**

*Gas*

1. What conditions must be applied to CO2 so it becomes **a supercritical fluid?**

*Increase pressure to at least 73 atm. The work done to increase the pressure will provide energy to heat up the sample enough to reach the minimum 31oC that will push it into the supercritical phase.*

1. **Considering the goal of NETs, why would you want to avoid applying heat to CO2 to assist in this transition to supercritical fluid?**

*Applying heat would require energy. This would work against the goal of negative emissions because the energy applied would likely come from an emission source. It would also require energy to pressurize the sample, but that is one of the disadvantages that has to be weighed. If it takes too much energy to do that, this will not be an effective technology.*

**Questions for Further Learning**

1. **Choose one NET. Identify the advantages and disadvantages of using this technology. Then explain how scientists and engineers should weigh the pros and cons to decide whether this technology should be used on a large scale.**

*The chart on page 15 is a good starting point. Students should discuss that most technologies will have positives and negatives that must be evaluated in order to determine efficiency and usefulness.*

1. **The graphic on page 12 contains a quote that says: “We have technologies to remove greenhouse gases from air, but it’s less clear whether we can scale them fast enough to make a difference.”**
   1. **What does it mean to scale these technologies?**

*Scaling is a process of taking a system that works in one setting and making it work in a much larger or smaller setting.*

* 1. **Why would it be difficult to scale the technologies?**

*Due to bulk properties of materials and unavoidable conditions, processes and chemical reactions don’t always work the same in different scales. When testing the ideas, scientists and engineers likely experimented with small-scale versions of the technologies and processes. In order for them to be useful, they would have to be scaled up by several orders of magnitude, which could affect their efficiency and negate their usefulness.*

1. **You may have seen advertisements for the Impossible Burger, which is described as the meatless burger, or meat made from plants. This company’s mission begins with the goal, “To drastically reduce humanity’s destructive impact on the global environment by completely replacing the use of animals as a food production technology.” How does meat production increase our carbon footprint?**

*As mentioned in the Carbon Footprint textbox, the processing associated with animal food production is quite high, due to a large amount of water and land use. The link from the textbox,* [*https://earthday.org/foodprint*](https://earthday.org/foodprint)*, is a good source of information on the impact of a variety of different kinds of food and why some have higher or lower impacts.*

**Graphic Organizer Rubric**

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

# Additional Resources

**Labs and demos**

Greenhouse Gas Simulation: This laboratory activity can be used to simulate greenhouse gases.

<https://teachchemistry.org/classroom-resources/greenhouse-gas-simulation>

Finding CO2 Mass in your Breath: A lab activity to trap carbon dioxide from your breath in a limewater solution. This connects to the mineralization technology.

<https://teachchemistry.org/classroom-resources/finding-co2-mass-in-your-breath>

Alka-Seltzer & Gas Solubility: A lab activity about the solubility of CO2 in water. This can be used as a connection to the idea of carbon storage, as oceans are a large CO2 sink.

<https://teachchemistry.org/classroom-resources/alka-seltzer-gas-solubility>

**Lessons and lesson plans**

Calculating Your Carbon Footprint: This lesson ties very nicely to the article. It addresses climate change and guides students toward calculating their carbon footprint.

<https://teachchemistry.org/classroom-resources/calculating-your-carbon-footprint>

Carbon, Carbon Everywhere: This lesson on the carbon cycle is geared for middle school, but can be implemented with high school students.

<https://teachchemistry.org/classroom-resources/carbon-carbon-everywhere>

Ideal Gas Law using Carbon Dioxide: A lesson that uses CO2 to teach the ideal gas law. <https://teachchemistry.org/classroom-resources/ideal-gas-law-using-carbon-dioxide>

Finding Chemistry Connections in Climate Change: Article from *Chemistry Solutions* that suggests several ways to link chemistry and climate change in lessons.

<https://teachchemistry.org/periodical/issues/may-2017/finding-chemistry-connections-in-climate-change>

**Projects and extension activities**

* Construct an argument to propose funding for one NET you think has the potential for greatest success. This can be done by assigning students to different regions of the country or the world to allow for various types of arguments.
* Hold a debate, town meeting, or board meeting to develop a plan for implementing one or more NET with different kinds of parameters, such as: using a specific budget, considering a specific region, as a board member of a national or international industrial company, or as an environmental activist.
* Design an industrial scale plan or prototype for one NET. This is a great opportunity to use the Design Cycle to meet NGSS Science & Engineering Practices. Students need to study the technology enough to understand its limitations and requirements to make the design.
  + In a chemistry class, it might be easier to select one technology that best matches a given unit, so studying the technology goes with studying the unit concepts.
    - Chemical reactions for the mineralization method
    - Phases of matter or gases for the geological sequestration
    - Chemical reactions with thermochemistry for bioenergy or plant growth
    - Structure of matter or materials with air capture

# Chemistry Concepts, Standards, and Teaching Strategies

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

* Chemistry Basics – physical properties
* Reactions & Stoichiometry – chemical change; conservation of matter
* States of Matter – phase changes; phase diagram; sublimation

**Correlations to Next Generation Science Standards**

This article can be used to achieve the following performance expectations of NGSS:

**HS-ESS3-4**

Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

**HS-ESS3-5**

Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth’s systems.

**HS-ESS3-6**

Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

**Disciplinary Core Ideas**:

* PS1.A: Structure and Properties of Matter
* ESS3.C: Human Impacts on Earth Systems
* ESS3.D: Global Climate Change

**Crosscutting Concepts:**

* Systems and System Models
* Cause and Effect: Mechanism and explanation
* Stability and Change

**Science and Engineering Practices:**

* Analyzing and interpreting data
* Constructing explanations (for science) and designing solutions (for engineering)
* Engaging in argument from evidence

**Nature of Science:**

* Scientific knowledge is based on empirical evidence.
* Scientific investigations use a variety of methods.

Student Reading Comprehension Questions – connections to NGSS Crosscutting Concepts:

* Q4: Structure and Function
* Q5: Systems and System Models + Stability and Change + Cause and Effect
* Q6: Patters + Systems & System Models
* Q7: Structure and Function
* Q4: Structure and Function
* Q8: Energy and Matter-Flows + Cycles and Conservation
* Questions for Further Learning Q1: Q7: Scale, Proportion, and Quantity

**Correlations to Common Core State Standards**

See how *ChemMatters* correlates to the[**Common Core State Standards**](https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html)  at www.acs.org/chemmatters.

**Teaching Strategies**

Consider the following tips and strategies for incorporating this article into your classroom:

* Alternative to the Anticipation Guide: Before reading, have a discussion and ask students for their ideas about removing CO2 from the atmosphere. Ask what problems might be encountered in removing CO2. As they read, students can compare their original ideas with information in the reading.
* After reading, ask students what they found most interesting or surprising from reading article.
* Chemical reactions: This article can start off a unit of chemical reactions using mineralization as a way of introducing synthesis reactions.
* Gases or covalent bonding: This article can be the anchor for a series of lessons on small molecules, what they are made of, how they bond, and effects they have in the atmosphere.
* Phases: This can be a good transition between lessons on liquids/solids and lessons on gases, with the phase diagram linking the topics together and showing why it is difficult to simply collect the CO2 from the air.