

ChemMatters®

Demystifying Everyday Chemistry

Teacher's Guide

OCTOBER 2021

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Teacher's Guide

What's the Deal with Climate Change?

October 2021

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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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. Climate change leads to loss of sea ice, more intense heat waves and droughts, and rising sea levels.
		2. The scientific community recognized that large-scale burning of fossil fuels affects climate about 10 years ago.
		3. The 10 warmest years on record occurred in the past 16 years.
		4. The most abundant gas in the atmosphere is oxygen (O ₂).
		5. Carbon dioxide (CO ₂) traps infrared radiation.
		6. Methane and halogen-containing gases used as refrigerants are less potent greenhouse gases than CO ₂ .
		7. Clouds increase warming of Earth's surface.
		8. Warming permafrost areas increases methane emissions which increases global warming.
		9. Plants capture carbon before it reaches the atmosphere.
		10. Sustainable energy technologies such as wind and solar power can help reduce global warming.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Why was the Intergovernmental Panel on Climate Change developed?
2. What is the primary driver of climate change?
3. List three global problems cause by climate change.
4. Define radiative efficiency.
5. Explain the difference between positive feedback and negative feedback in terms of climate change.
6. Define global warming potential.
7. How much did the average level of CO₂ in the atmosphere change from 2020 to April of 2021?
8. Give the proportion of the 20 year global warming potential of N₂O as compared to CO₂.
9. Which greenhouse gas makes up a small percentage of warming gases but has the greatest global warming potential compared to CO₂?
10. How does CO₂ impact climate if it is such a small percentage of the atmosphere?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Explain how the increased warming of permafrost is an example of positive feedback in the climate system.
2. In the mid-1900's the level of CO₂ in the atmosphere rose to 300ppm. Explain what the measure 300 ppm means.
3. Research one promising technology for removing CO₂ from the atmosphere. Write a paragraph explaining the way the method would remove CO₂ and draft a proposal for how this technology might function in your community.
4. The article mentions that to keep global warming below 2°C we will need to utilize conventional abatement technologies, emitting technologies, and carbon removal technologies. Research and describe two abatement technologies that prevent CO₂ from entering the atmosphere.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe what we know about climate change, how we know it is happening, and what can be done to slow the change.

Questions	Evidence	Reasoning linking claim to evidence
How do we know climate change is happening?		
Why is CO ₂ a particular problem?		
What are some problems caused by climate change?		
What can we do to prevent temperatures from rising further?		

Summary: On the back of this sheet, write a short email to a friend describing three things you can do to help prevent further global warming..

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Why was the Intergovernmental Panel on Climate Change developed?

The Intergovernmental Panel on Climate Change was established to assess the science around climate change.

2. What is the primary driver of climate change?

The rising levels of carbon dioxide released by burning fossil fuels is one of the primary drivers of climate change.

3. List three global problems caused by climate change.

Three problems caused by climate change are loss of sea ice, more intense heat waves and droughts, and rising sea levels.

4. What is radiative efficiency?

Radiative efficiency is a measure of how readily matter absorbs energy in the infrared.

5. Explain the difference between positive feedback and negative feedback in terms of climate change.

Positive feedback reinforces warming while negative feedback reduces warming.

6. Define global warming potential.

Global warming potential is a measure of how much energy a greenhouse gas would add to the atmospheric warming in a given time compared to CO₂.

7. How much did the average level of CO₂ in the atmosphere change from 2020 to April of 2021?

The average level of CO₂ increased 3.5 ppm from 2020 to April of 2021.

8. Give the proportion of the 20 year global warming potential of N₂O as compared to CO₂.

The 20 year GWP for N₂O is 289 times greater than that of CO₂.

9. Which greenhouse gas makes up a small percentage of warming gases but has the greatest global warming potential compared to CO₂?

Sulfur Hexafluoride has the greatest global warming potential.

10. How does CO₂ impact climate if it is such a small percentage of the atmosphere?

CO₂ is a greenhouse gas that absorbs thermal infrared radiation and raises atmospheric temperatures.

Questions for Further Learning

1. Explain how the increased warming of permafrost is an example of positive feedback in the climate system.

The increased warming of permafrost is an example of positive feedback because as the permafrost melts, methane, a greenhouse gas, is released into the atmosphere where it contributes to climate warming.

2. In the mid-1900's the level of CO₂ in the atmosphere rose to 300ppm. Explain what the measure 300 ppm means.

300 ppm means that for every one million molecules of dry air, there were on average 300 CO₂ molecules.

3. Research one promising technology for removing CO₂ from the atmosphere. Write a paragraph explaining the way the method would remove CO₂ and draft a proposal for how this technology might function in your community.

Student responses will vary.

4. The article mentions that to keep global warming below 2°C we will need to utilize conventional abatement technologies, emitting technologies, and carbon removal technologies. Research and describe two abatement technologies that prevent CO₂ from entering the atmosphere.

Student responses will vary.

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 Lab”](#): In this lab activity students will test the greenhouse potential of water vapor and carbon dioxide.

Simulations

[“The Greenhouse Effect”](#): This PhET simulation allows students to investigate the interaction of photons with atmospheric gases, which can assist them in explaining why greenhouse gases affect temperature.

Lessons and lesson plans

[“Climate Change and the Keeling Curve”](#): This ACS lesson plan includes inquiry-based activities designed to help students identify how scientists developed an understanding of global warming by using evidence collected over decades.

[“Visualizing and Understanding the Science of Climate Change”](#): This site provides eight interactive lessons to help students understand climate change, climate feedback loops, and the impact of climate change, and how to respond to climate change. The lessons include vocabulary and simulations and are written so students can work through them on their own or as a class.

Projects and extension activities

[“Solving the Carbon Dioxide Problem”](#): In this activity students are asked to review data in order to construct a plan to reduce and remove carbon dioxide from the atmosphere.

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Chemical change
- Physical properties
- Renewable energy
- Observations
- Gases

Correlations to Next Generation Science Standards

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

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- ESS2.A: Earth Materials and Systems
- ETS1.C: Optimizing the Design Solution
- Stability and change
- Systems and system models

Science and Engineering Practices:

- Developing and using models
- Analyzing and interpreting data

Crosscutting Concepts:

- Cause and effect
- Energy and matter

Nature of Science:

- Scientific knowledge is based on empirical evidence.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students what they know about climate change, and what can be done to fight it. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about greenhouse gases, climate change, and how to combat climate change.
- After students have read and discussed the article, consider showing the ACS Reactions Video “How Chemistry Makes Carbon Dioxide Removal Possible” (7:39) at <https://youtu.be/wu3hoo3p4Kk>. After the video, challenge the students to think of other methods to remove carbon dioxide from the atmosphere.

Teacher's Guide

Why a Pennsylvania Town has been Burning for 60 Years

October 2021
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Anticipation Guide

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Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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
		The Centralia fire began when trash was burned in a makeshift landfill.
		Coal is a type of metamorphic rock.
		There are three types of coal, each with different amounts of carbon content.
		Coal contains sulfur which is removed by using aqueous limestone when it is burned at power plants.
		All chemical reactions require activation energy to get started.
		Coal produces more kJ/g of energy than methane.
		For a fire to continue to burn, its temperature must remain above the ignition temperature of the fuel.
		Carbon monoxide is a colorless, odorless gas that can cause nausea, drowsiness, and death.
		Currently there are fewer than 10 underground fires in Pennsylvania.
		A mountain in Australia has burned for 6000 years.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Which element is always in a combustion reaction? What are the two most common products in a combustion reaction?
2. State and give a brief description of the four parts of the tetrahedron of fire?
3. In terms of chemical bonds broken vs. chemical bonds formed, how is a chemical reaction exothermic?
4. How is coal naturally formed? What are the 2 main elements in coal?
5. Describe how scrubbers work. What are the final products made from this process?
6. How does the foam in a fire extinguisher put out a fire?
7. Compare the energy from wood and coal. Which would provide more heat when burned? Explain your answer in terms of heat of combustion. What other fuels would produce more heat?
8. Explain the heat transfer in the process of evaporation. How does this cool down hot objects (or fire)
9. In terms of evaporation, explain how sweating cools a person down during and after exercise.
10. State at least 1 way to remove each of the 4 components of the tetrahedron of fire in order to extinguish the fire.
11. How does ignition temperature in a combustion reaction relate to the activation energy in the reaction?
12. What does carbon monoxide (CO) do in the body that makes it dangerous to humans?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Carbon dioxide and sulfur oxides are commonly produced by the burning of coal. Research and explain how these gases react in the atmosphere and affect our climate.
2. The demand and use of coal has been greatly diminished over time. Think of one or two other forms of energy that we use now. Research the pros and cons of this/these energy sources.

Name: _____

Graphic Organizer

Directions: As you read, complete the graphic organizer below to describe the factors contributing to the long-burning fire, and issues faced by Centralia residents once the fire began.

Issue	Description, including chemicals involved
Why the type of coal matters	
Why the fire is still burning after 60 years	
Hazards of burning coal	
Attempts to extinguish the fire and why they did not work	

Summary: On the back of this sheet, write a one-sentence summary (15 words or less) describing what you learned from the article.

Answers to Reading Comprehension Questions, Graphic Organizer Rubric, & EdPuzzle

1. Which element is always in a combustion reaction? What are the two most common products in a combustion reaction?

All combustion reactions include the element oxygen, because that is one of the components for fire. Carbon and hydrogen are present in combustions of organic compounds. The 2 most common products is typically carbon dioxide (CO_2) and water (H_2O).

2. State and give a brief description of the four parts of the tetrahedron of fire?

The four parts of the tetrahedron of fire:

- Oxygen –used to oxidize the fuel to produce the fire
- Heat- enough is needed to get the material to its ignition temperature to create fire
- Fuel- the chemical that is oxidized and produces the heat for fire
- Chain Reaction - self-sustaining to keep the fire going

3. In terms of chemical bonds broken vs. chemical bonds formed, how is a chemical reaction exothermic?

In an exothermic reaction, heat is released. This is because the energy released by the formation of product's chemical bonds is greater than the energy absorbed to break the reactant chemical bonds.

4. How is coal naturally formed? What are the 2 main elements in coal?

Coal is formed from the remains of plants from millions of years ago. High pressures and temperatures convert the plant material into coal. The two main elements in coal are carbon (C) and hydrogen (H).

5. Describe how scrubbers work. What are the final products made from this process?

A scrubber is a chemical process that converts the poisonous gases (like SO_2) to harmless products (gypsum). Typically, the harmful gases are passed through aqueous limestone to produce the gypsum.

6. How does the foam in a fire extinguisher put out a fire?

The foam in a fire extinguisher would smother the fire, meaning that the fuel would be cut off from the oxygen supply (like when they added the fly ash to the coal mines in Centralia).

7. Compare the energy from wood and coal. Which would provide more heat when burned? Explain your answer in terms of heat of combustion. What other fuels would produce more heat?

The heat of combustion is much greater for coal than it is for wood (-32.8 kJ/g vs. -17.3 kJ/g), so coal produces more heat when burned. Methane (natural gas) produces even more than both coal and wood (-55.5 kJ/g), so it would be a better fuel to use for energy.

8. Compare the energy from wood and coal. Which would provide more heat when burned? Explain your answer in terms of heat of combustion. What other fuels would produce more heat?

In evaporation, the evaporating substance absorbs the heat and turns into gas, and escapes. The remaining substance has less heat (kinetic energy), thus the temperature drops. (in terms of fire, the temperature would drop below the ignition temperature).

9. In terms of evaporation, explain how sweating cools a person down during and after exercise.

When a person sweats, the sweat (water) in the body absorbs the excess body heat. When the sweat evaporates (or is wiped off), the excess heat is also removed from the body. The result is an overall lower body temperature.

10. State at least 1 way to remove each of the 4 components of the tetrahedron of fire in order to extinguish the fire.

Ways to remove one of the four components of fire:

- Oxygen – smother the fire with a towel or other substance that will cut off the oxygen supply
- Heat- add water or other cool, non-flammable materials to lower the temperature below the ignition point
- Fuel- remove any unreacted fuel material before it reaches the ignition temperature
- Chain Reaction - surround or contain the source of the fire, and keep the flames away from anything else flammable.

11. How does ignition temperature in a combustion reaction relate to the activation energy in the reaction?

The activation energy in a reaction is the minimum amount of energy (usually heat) that is needed for the reactants to start the reaction. The ignition temperature is the temperature where enough heat is present to start a fire. Both are minimum amounts of energy to start the reactions.

12. What does carbon monoxide (CO) do in the body that makes it dangerous to humans?

Carbon monoxide will attach to the hemoglobin in blood, instead of oxygen. When less oxygen attaches to the hemoglobin, which will affect the health of a person.

Questions for Further Learning

1. Carbon dioxide and sulfur oxides are commonly produced by the burning of coal. Research and explain how these gases react in the atmosphere and affect our climate.

Carbon dioxide would react with the water in lakes (or air) to produce carbonic acid (HCO_3). Sulfur oxides will react with water to make sulfuric acid (H_2SO_4). These would create high levels of acidity in lakes and rivers that could have detrimental effects to aquatic life. Also, this is how acid rain is created.

(Note: all nonmetal oxides react with water to make acids. All metal oxides react with water to make bases.)

2. The demand and use of coal has been greatly diminished over time. Think of one or two other forms of energy that we use now. Research the pros and cons of this/these energy sources.

Answers will vary.

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.
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0	Not acceptable	So incomplete that no judgment can be made about student understanding

EdPuzzle Answers

Check out *ChemMatters'* first EdPuzzle, based on an ACS Reactions video on the Centralia mine fire, and assign it to your students:

<https://edpuzzle.com/media/6116963bddcd16413857c880>

1. What do you think are some reasons for the big drop in coal demand?

In the mid 1900's, oil and natural gas became more popular for automobiles and heating. This was also the time the 1st nuclear power plant was built to produce electricity (see:

<https://www.energy.gov/ne/articles/9-notable-facts-about-world-s-first-nuclear-power-plant-ebi>).

2. What is the leading theory on how the coal fire in Centralia started?

Burning trash

3. What happens at a substance's ignition temperature?

The fuel/substance has enough energy to react with oxygen. The substance will then burn.

4. How do increases in sulfur gases and carbon monoxide affect people?

When people inhale these gases, they could cause damage to lungs or other organs. (See the article to explain how CO affects the body).

5. How do you think wet sand would extinguish a fire?

The wet sand would cool the coal below its ignition point, as well as smother the flames thus cutting of the oxygen.

6. Although natural coal fires are quite common, what could we do to prevent human-made coal fires?

Answers may vary.

Additional Resources

Labs and demos

Combustion of food lab from Flinn. This activity will introduce the concept of calorimetry and investigate the caloric content of snack foods.

<https://www.flinnsci.com/api/library/Download/f9560a5fc7ef4a6b8f4598fea30626eb>

Simple Evaporation Experiments. Fun and simple evaporation experiments students can do--even at home--to learn more about evaporation.

<https://sciencing.com/simple-evaporation-experiments-15764.html>

Exothermic/Endothermic Lab. In this lab, students determine whether mixing two chemicals is endothermic or exothermic. One is a physical change, one is a chemical change.

<https://teachchemistry.org/classroom-resources/exothermic-and-endothermic-lab>

Lessons and lesson plans

EPA coal/acid rain. Information about acid rain from the U.S. EPA, including games and an animation.

https://www3.epa.gov/acidrain/education/site_students/whatcauses.html#:~:text=Power%20plants%20release%20the%20majority,These%20pollutants%20cause%20acid%20rain.

Fire Triangle/Fire Tetrahedron. A deeper dive into how the fire triangle became the fire tetrahedron, and what it means.

<https://www.thinkreliability.com/InstructorBlogs/Blog%20-%20Fire.pdf>

AACT Activity: Biofuels of the Future. This lesson has students exploring the world of automobile alternative energy sources through the study of biofuels.

<https://teachchemistry.org/classroom-resources/biofuels-of-the-future>

AACT Activity: What Makes Something Feel Warm. In this lesson students actively engage in thinking about energy issues in chemistry and the nature of energy (thermal) transfer.

<https://teachchemistry.org/classroom-resources/what-makes-something-feel-warm>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Activation energy
- Exothermic and endothermic
- Heat of combustion
- Chemical change

Correlations to Next Generation Science Standards

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

HS-PS1-4. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends on the changes in total bond energy.

HS-ETS1-3.

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraint, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Structure and function
- Scale, proportion, and quantity
- Energy and matter

Science and Engineering Practices:

- Planning and carrying out investigations

Nature of Science:

- Scientific knowledge assumes an order and consistency in natural systems.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students what they know about coal mining and the hazards involved. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about coal mining and why the fire in Centralia is still burning.
- The ACS Reactions Video “Why This Town Has Been on Fire for 50 Years,” produced in 2015, has more information about the Centralia fire. You can find it at <https://youtu.be/fsgqy5FYP2c>. Consider sharing this video with students after they have discussed the article. Ask them what information is in the video that was not in the article. We also turned this video into an EdPuzzle for your convenience! <https://edpuzzle.com/media/6116963bddcd16413857c880>

Teacher's Guide

Science Solves the Mystery of an Ancient, Deadly Ritual

October 2021 Table of Contents

Anticipation Guide **23**

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

Reading Comprehension Questions **24**

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 **27**

This helps 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 **28**

[Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.](#)

Additional Resources **33**

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Chemistry Concepts, Standards, and Teaching Strategies

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Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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
		In 2013, birds flying near a cave in an ancient sunken arena were instantly killed.
		The gas emitted from the cave in the arena was analyzed using infrared radiation (IR).
		The air we breathe contains about 1% of CO ₂ .
		The CO ₂ levels above the arena’s sanctuary floor varied with both the time of day and the height above the ground.
		Humans need O ₂ for respiration.
		Energy produced during respiration is stored in cells by ATP (adenosine triphosphate).
		CO ₂ kills through poisoning the victim.
		³ He is commonly found in Earth’s crust.
		CO ₂ is lighter than air.
		Scientists’ findings support the report of the geographer and philosopher Strabo from the first century B.C.E.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

Read ONLY the first four paragraphs, then answer question 1.

1. After reading or listening to the introduction to the story, develop one specific hypothesis that could potentially explain why the animals died, while the priests did not, when entering the portal in the Plutonium. Your hypothesis must include scientific reasoning to explain why the hypothesis is plausible.

Read the remainder of the intro and the first 3 paragraphs of “What Makes This Cave So Deadly?”, then answer question 2.

2. Imagine that you are at the Plutonium with Hardy Pfanz and colleagues. You are standing in the arena, looking at the location of the portal that leads to the cave that is soon to be unearthed. Describe one test that you would do to decide whether your hypothesis has merit or if you should develop a new hypothesis. Describe what you would do and how the findings would help you know whether to continue testing your initial hypothesis. You do not need to know the names of equipment or tests. Just describe what you want to do and what you want to find out.

Read the remainder of the article while answering the following questions:

3. Pfanz’s hypothesis is not stated, but the article describes the initial test. In the same way that you wrote your own hypothesis in question 1, write a hypothesis that Pfanz could have been attempting to test with the IR analyzer.
4. IR light and visible light can both be used to analyze gases. Absorption of one kind of light affects how the bonds vibrate and absorption of the other affects the energy states of electrons. The scientists used IR radiation to analyze the cave gases.
 - a. Which range of light has higher energy photons, visible or infrared?
 - b. Based on your answer to (a), were the scientists studying bond vibrations or electron energy levels for the gases in the cave?
 - c. Draw Lewis structures for each of the three major gases found in the cave.
 - i. Which molecule likely has the shortest bond length? Explain.
5. The three most abundant gases in the cave are the same three gases that are the most abundant in our atmosphere.
 - a. In what way does the composition of these gases in the cave differ from the composition of the atmosphere outside of the cave?
 - b. Why is the cave atmosphere deadly, when the same three gases are not deadly in our atmosphere?
 - c. What is it about the carbon dioxide that makes it deadly in this case?

Student Reading Comprehension Questions, cont.

6. Consider the respiration equation shown.
 - a. Summarize the process of ATP being hydrolyzed to ADP by writing a chemical equation that includes only molecular formulas, rather than structural formulas. (You can use "ATP" and "ADP", rather than the full chemical formulas for these. Your final equation should contain 5 different species.
 - b. Carefully note the changes in bonding when ATP reacts to form ADP. Write the steps as though you were using a model kit to model the reaction. Identify which bonds must be broken and formed to accurately represent the overall process using as few steps (with your model kit) as possible.
 - c. Are there more bonds broken or more bonds formed?
 - d. Explain how the above situation can lead to a release of energy when ATP hydrolyzes to ADP.

7. Carbon dioxide levels in the atmosphere are relatively consistent within a given region. How is it possible that levels vary with height inside the relatively small region inside the cave?
 - a. What is the property of carbon dioxide that allows for this layered concentration effect?

8. Choose any relevant chemistry concept to describe a mechanism that accounts for the carbon dioxide levels in the cave differing from night to day.

9. Pfanz and the team used isotope ratios to confirm the assumed source of the extra carbon dioxide in the cave.
 - a. Write the full isotope notation for each of the two stable isotopes of helium.
 - b. Most of the helium-3 found in the earth has been present since Earth's formation, but helium-3 can also be produced by the beta decay of tritium (hydrogen-3). Write the nuclear equation that defines this radioactive process.
 - c. Using the periodic table, identify the atomic mass of helium. Explain, using this value, which of the two isotopes must be more abundant throughout the earth.
 - d. Following is a data table of simulated data that may have been taken while studying the gases in the cave.

Atmospheric Concentration of Gas:	Outside of Cave	Inside of Cave
CO ₂	410 ppm	8.90 x 10 ⁵ ppm
⁴ He	5.12 ppm	4.98 ppm
³ He	7.01 x 10 ⁻⁶ ppm	1.36 x 10 ⁻⁴ ppm

Make a claim about the reason for the extra carbon dioxide inside the cave. Explain how this data can be used as evidence to support your claim.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

10. Research the “fire triangle” or “fire tetrahedron” and use it to explain how a CO₂ fire extinguisher works.

11. A CO₂ fire extinguisher is filled to a pressure of 825 psi.
 - a. What is the value of this pressure in atmospheres?
 - b. Consult a phase diagram to determine what state of matter the CO₂ in the fire extinguisher is in while at room temperature. Explain your answer.
 - c. Though a CO₂ fire extinguisher can put out a grease fire, it is not recommended for this use because it can do more harm than good. Imagine standing in a kitchen where a grease fire has just arisen. Propose an explanation for why you should not use a CO₂ fire extinguisher in this situation. Use the term “atmospheric pressure” in your answer.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the sources and properties of carbon dioxide in the ancient arena.

	Broad answer	Details
Significance of location of the Plutonium arena		
How analysis of gases inside the cave was done		
How CO ₂ can kill		
How source of CO ₂ was confirmed		

Summary: On the back of this sheet, write a short email to a friend describing how science confirmed the mystery of the arena in Hierapolis.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. After reading or listening to the introduction to the story, develop one specific hypothesis that could potentially explain why the animals died, while the priests did not, when entering the portal in the Plutonium. Your hypothesis must include scientific reasoning to explain why the hypothesis is plausible.

Students should proposed possible explanations, with some kind of reasoning. Example: The vapors are deadly to animals, but not to people, because there are other examples of things that affect one species, but not another.

2. Imagine that you are at the Plutonium with Hardy Pfanz and colleagues. You are standing in the arena, looking at the location of the portal that leads to the cave that is soon to be unearthed. Describe one test that you would do to decide whether your hypothesis has merit or if you should develop a new hypothesis. Describe what you would do and how the findings would help you know whether to continue testing your initial hypothesis. You do not need to know the names of equipment or tests. Just describe what you want to do and what you want to find out.

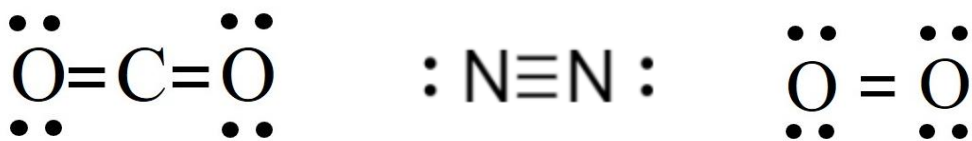
Students should describe anything that is consistent with the hypothesis they made above. Example for the above hypothesis: Use a tube to go through the layer leading to the tunnel and collect a sample of the atmosphere in the cave. Then inject this sample into a controlled environment containing some kind of test animal to see if the animal lives or dies.

3. Pfanz's hypothesis is not stated, but the article describes the initial test. In the same way that you wrote your own hypothesis in question 1, write a hypothesis that Pfanz could have been attempting to test with the IR analyzer.

Students should use information from the article to state this. Example: Carbon dioxide may be the gas that is killing the animals because other animals have been affected by carbon dioxide levels from volcano activity.

4. IR light and visible light can both be used to analyze gases. Absorption of one kind of light affects how the bonds vibrate and absorption of the other affects the energy states of electrons. The scientists used IR radiation to analyze the cave gases.
 - a. Which range of light has higher energy photons, visible or infrared? *Visible*
 - b. Based on your answer to (a), were the scientists studying bond vibrations or electron energy levels for the gases in the cave? *Students need to consider that it would take more energy to change the energy level of an electron than it would to jiggle a bond, so the answer to (a) tells them that the IR radiation Phanz used is the lower of the two possibilities, thus concluding that the scientists used IR to study bond vibrations.*
 - c. Draw Lewis structures for each of the three major gases found in the cave.
 - i. Which molecule likely has the shortest bond length? Explain.

From the pie chart, the three gases are CO₂, N₂, and O₂.



N₂ would have the shortest bond length because it has the highest bond order (triple bond) and all of the involved elements are in the same period and thus similar enough in radius to make that distinction.

5. The three most abundant gases in the cave are the same three gases that are the most abundant in our atmosphere.

- a. In what way does the composition of these gases in the cave differ from the composition of the atmosphere outside of the cave?

In the cave, the most significant difference is that the amount of carbon dioxide is significantly higher than the very small percentage found in our atmosphere.

- b. Why is the cave atmosphere deadly, when the same three gases are not deadly in our atmosphere?

21% of our atmosphere is made of oxygen gas, while in the cave that number drops to 4%. This smaller amount does not allow our bodies to retrieve from the atmosphere the amount of oxygen we need to survive.

- c. What is it about the carbon dioxide that makes it deadly in this case?

The higher amount of carbon dioxide basically replaces the needed oxygen for a body to survive. The high density of carbon dioxide means that its concentration on the ground is even higher than at higher levels where the air would be breathed in. This means that after losing consciousness, an animal (or person) would collapse to the ground and be further deprived of the oxygen.

6. Consider the respiration equation shown.

- a. Summarize the process of ATP being hydrolyzed to ADP by writing a chemical equation that includes only molecular formulas, rather than structural formulas. (You can use "ATP" and "ADP", rather than the full chemical formulas for these. Your final equation should contain 5 different species.



- b. Carefully note the changes in bonding when ATP reacts to form ADP. Write the steps as though you were using a model kit to model the reaction. Identify which bonds must be broken and formed to accurately represent the overall process using as few steps (with your model kit) as possible.

Students may interpret this in several ways. It does not need to be mechanistically accurate! Summary is: Break a P-O single bond in ATP to leave PO₃ (don't worry about charge), Break one H-O single bond in water, form a P-O bond between the OH from water and the P from the end phosphate that was broken off in the first step.

- c. Are there more bonds broken or more bonds formed?

More bonds are broken than formed.

- d. Explain how the above situation can lead to a release of energy when ATP hydrolyzes to ADP.

Most important is to understand that breaking bonds requires energy input and forming bonds releases energy. If more bonds are broken than formed, then for the process to release energy, the bond that is formed must be much stronger than the bonds that were broken.

7. Carbon dioxide levels in the atmosphere are relatively consistent within a given region. How is it possible that levels vary with height inside the relatively small region inside the cave?

Different temperatures and air movement can affect this, but the CO₂ also is being released from the ground and the concentration there is higher than further up in height.

- a. What is the property of carbon dioxide that allows for this layered concentration effect?

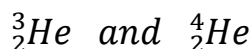
*Carbon dioxide has a higher **density** than air, so in a still environment like the cave, the dense CO₂ molecules can gather near the ground, pushing nitrogen and oxygen molecules up higher.*

8. Choose any relevant chemistry concept to describe a mechanism that accounts for the carbon dioxide levels in the cave differing from night to day.

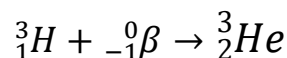
There are several options to explain this. The major one is that the higher temperatures in the daytime allow the CO₂ molecules to spread apart more, thus decreasing the concentration in the air. Cooler temperatures have the opposite effect and, along with density, help explain high concentrations near ground level.

9. Pfanz and the team used isotope ratios to confirm the assumed source of the extra carbon dioxide in the cave.

- a. Write the full isotope notation for each of the two stable isotopes of helium.



- b. Most of the helium-3 found in the earth has been present since Earth's formation, but helium-3 can also be produced by the beta decay of tritium (hydrogen-3). Write the nuclear equation that defines this radioactive process.



- c. Using the periodic table, identify the atomic mass of helium. Explain, using this value, which of the two isotopes must be more abundant throughout the earth.

The atomic mass of helium is 4.008 amu. Since this is a weighted average, there must be more helium-4 than helium-3 because the weighted average will be closer to the weight of the more abundant isotope.

- d. Following is a data table of simulated data that may have been taken while studying the gases in the cave.

Atmospheric Concentration of Gas:	Outside of Cave	Inside of Cave
CO ₂	410 ppm	8.90 x 10 ⁵ ppm
⁴ He	5.12 ppm	4.98 ppm
³ He	7.01 x 10 ⁻⁶ ppm	1.36 x 10 ⁻⁴ ppm

**Make a claim about the reason for the extra carbon dioxide inside the cave.
Explain how this data can be used as evidence to support your claim.**

Claim: The extra CO₂ in the cave comes from deep in the earth and is released during the movement of tectonic plates.

*Explanation: According to the data the ratio of ³He to ⁴He outside of the cave, which is assumed to be the natural ratio, is $\frac{7.01 \times 10^{-6} \text{ ppm}}{5.12 \text{ ppm}}$ or 1.37×10^{-6} (this is unitless, as it is a ratio, expressed in decimal form). The ratio of ³He to ⁴He inside the cave is $\frac{1.36 \times 10^{-4} \text{ ppm}}{4.98 \text{ ppm}}$ or 2.73×10^{-5} . Since the ratio inside the cave is **higher** than the normal ratio, this indicates that extra helium-3 is somehow entering the cave. It is known that both helium isotopes can travel with CO₂, and that helium-3 is found mostly in Earth's mantle, while helium-4 is found mostly in Earth's crust. The higher proportion of helium-3 is consistent with the hypothesis that the CO₂ in the cave is originating in the mantle.*

12. Research the “fire triangle” and use it to explain how a CO₂ fire extinguisher works.

The three points of the fire triangle are fuel (some kind of combustible material), oxygen (enough to sustain the combustion reaction), and a source of heat (enough to raise the temperature of the material to its ignition point, which is specific to each substance). All three must be present for a fire to occur. Carbon dioxide works by displacing the oxygen near the fire in hopes of decreasing it enough that it can no longer sustain combustion, thus removing one point of the triangle. (It will also come out of the hose at a very low temperature, which will assist in decreasing another point of the triangle, heat.)

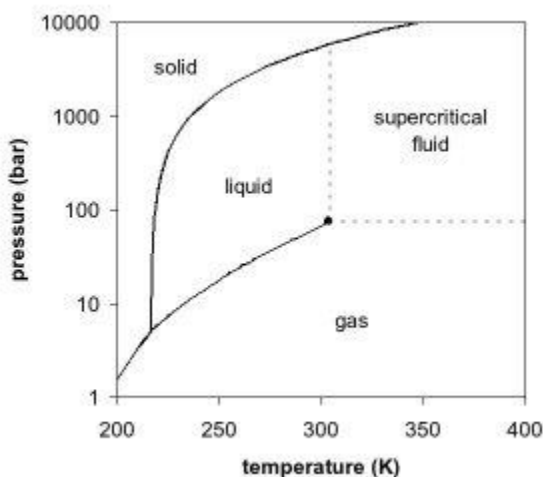
13. A CO₂ fire extinguisher is filled to a pressure of 825 psi.

- a. What is the value of this pressure in atmospheres?

$$825 \text{ psi} \times \frac{1 \text{ atm}}{14.7 \text{ psi}} = 56.1 \text{ atm}$$

- b. Consult a phase diagram to determine what state of matter the CO₂ in the fire extinguisher is in while at room temperature. Explain your answer.

The triple point is -57°C (216K) and 5.1 atm; The critical point is 31°C (304K) and 73 atm.



If the pressure in the fire extinguisher is 56.1 atm (~57 bar on shown graph), it is between the triple point pressure and the critical point pressure. If the temperature is “room temperature”, it is approximately 293 K and this is between the triple point temperature and the critical point temperature. This means it falls somewhere in the liquid or gas state on the chart. It is very close to being directly on the line between liquid and gas. You may not be able to find a phase diagram that is precise enough to make this distinction, but it would definitely be in gas form once the extinguisher is used and the pressure decreases even just a little.

Image Source: Wikimedia Commons

- c. Though a CO₂ fire extinguisher can put out a grease fire, it is not recommended for this use because it can do more harm than good. Imagine standing in a kitchen where a grease fire has just arisen. Propose an explanation for why you should not use a CO₂ fire extinguisher in this situation. Use the term “atmospheric pressure” in your answer.

The very high pressure in a CO₂ fire extinguisher (56.1 times the normal atmospheric pressure) means that the extinguishing material will shoot out of the hose extremely fast and with a lot of force. This force would hit the grease that is on fire and likely scatter it. Since grease is sticky, this scattered grease will

stick wherever it lands, thus spreading the one fire into many small fires that can land on flammable things like curtains and paper towels.

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

- PhET Simulated Lab Molecules and Light https://phet.colorado.edu/sims/html/molecules-and-light/latest/molecules-and-light_en.html

Simulations

- Density (how changing variables affects density) <https://teachchemistry.org/classroom-resources/the-density-simulation>
- What is Temperature? <https://teachchemistry.org/classroom-resources/what-is-temperature>

Lessons and lesson plans

- ACS Landmark Lesson Plans: Radiocarbon Dating and Willard Libby <https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/lesson-plans/radiocarbon-dating-willard-libby-lesson.html>
- ACS Landmark Lesson Plans: Mars Exploration with Infrared Spectrometers <https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/lesson-plans/mars-exploration-infrared-spectrometers-lesson.html>
- AACT Lesson: Finding CO₂ Mass in your Breath <https://teachchemistry.org/classroom-resources/finding-co2-mass-in-your-breath>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Physical properties
- Identifying an unknown
- Gases
- Radioactive isotopes

Correlations to Next Generation Science Standards

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

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.

HS-ESS2-3. Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

Disciplinary Core Ideas:

- LS1.C: Organization for matter and Energy Flow in Organisms
- ESS2.3: Plate Tectonics and Large-Scale System Interactions

Crosscutting Concepts:

- Cause and effect
- Energy and matter
- Stability and change

Science and Engineering Practices:

- Analyzing and interpreting data
- Engaging in argument from evidence

Nature of Science:

- Scientific knowledge is based on empirical evidence.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students what they know about carbon dioxide, and where it is found on or near Earth. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about carbon dioxide.
- After students have read and discussed the article, consider showing the ACS Reactions Video “UNTOLD: The Invisible Tsunami that Killed 1500 People in One Night” (11:28) at <https://youtu.be/rNKDx3kR3tk>. The video describes how carbon dioxide gas suddenly released from Lake Nyos in Cameroon killed 1500 people in 1986.

Teacher's Guide

Copying Nature to Fight Climate Change

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Anticipation Guide **36**

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

Reading Comprehension Questions **37**

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 **39**

This helps 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 **40**

[Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.](#)

Additional Resources **43**

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

Chemistry Concepts, Standards, and Teaching Strategies **44**

Anticipation Guide

Name: _____

Directions: *Before reading the article*, in the first column, write “A” or “D,” indicating your Agreement or Disagreement 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
		All living organisms on Earth depend on photosynthesis.
		Plants remove O ₂ from the atmosphere.
		Catalysts are required for photosynthesis.
		The carbon cycle includes carbon going back and forth between the atmosphere and rocks and soil.
		Today hydrogen fuel cells are produced in a process that emits CO ₂ into the atmosphere.
		To separate water into hydrogen and oxygen requires electric energy.
		Artificial leaf researchers are trying to produce ethanol and butanol to use as fuel.
		Chlorophyll makes plants appear green because it absorbs green light.
		Artificial leaf devices that currently exist are larger than a football field.
		Researchers are using non-photosynthetic bacteria to produce acetic acid to make fuels.

Student Reading Comprehension Questions

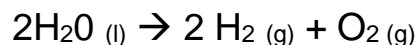
Name: _____

Directions: Use the article to answer the questions below.

1. Write the balanced chemical equation for photosynthesis and respiration.
2. How does the process of photosynthesis work in harmony with humans to create a seesaw type balance in our world?
3. Explain how humans have affected the carbon cycle.
4. List some of the most significant challenges engineers of the artificial leaf most overcome to make synthetic photosynthesis a mainstream energy source.

Connecting Concepts

5. Compare and contrast oxidation and reduction and identify which element is being oxidized and reduced in the electrolysis of water equation shown below:



6. Using the balanced chemical reaction for photosynthesis from question 1, prove mass (thus matter) was conserved during the chemical equation.
7. All plants and trees start as tiny seedlings; over time they grow to their mature form. For example, the primary source of mass in a tree is from carbon. What is the source of the carbon that allows a tree to grow?
8. What are some environmental advantages artificial leaf technology has over other sources of green energy such as ethanol fuel, wind, and solar?

Student Reading Comprehension Questions, cont.

Write your answers on another piece of paper if needed.

9. The article mentions catalyst and their importance to both the natural and artificial photosynthesis process. What is a catalyst? How do catalysts increase the rate of a chemical process?

Questions for Further Understanding and Exploration

Write your answers on another piece of paper if needed.

10. The article states economists project the economic damages from climate change will reach \$1.7 trillion dollars per year by 2025 and roughly \$30 trillion per year by 2075. In detail, explain how global climate change can cause economic (financial) damage.

11. Artificial leaf technology has the potential to deliver a large amount of clean, sustainable energy with a small environmental footprint. Today is common to see solar panels and windmills in various parts of the country. Some people may argue that solar panels and windmills are not aesthetically pleasing. Propose a method to incorporate artificial leaf technology into the environment in an aesthetically pleasing manner. Create a model or diagram to support your answer.

12. You are hired as marketing VIP for a leading artificial leaf technology start up company. Your task is to create a 30 second TV commercial to promote your product and encourage consumers to purchase and artificial leaf system for their property to power their home. You have control over the design of the leaf system and how residents may incorporate it onto their property. Use your smartphone to record the commercial and share your finish product with your teacher.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to compare photosynthesis in plants with artificial leaf technology.

	Green Plants	Artificial leaf technology
Reactants		
Products		
Catalysts		
Energy input		
Efficiency		
Fuels produced		
Future directions		

Summary: On the back of this sheet, write a tweet (280 characters or less) to a friend about how artificial leaf technology could help alleviate climate change.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Write the balanced chemical equation for photosynthesis and respiration.

Photosynthesis: $6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2$

Respiration: $\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{energy}$

2. How does the process of photosynthesis work in harmony with humans to create a seesaw type balance in our world?

Humans produce a large amount of carbon dioxide through respiration (breathing) and the consumption of fossil fuels. Plants, through photosynthesis, consume the carbon dioxide, and produce oxygen. As we know, oxygen is essential for humans and animals for the respiration process. Together, when balanced, plants and humans provide useful fuel for one another to maintain a healthy and productive environment.

3. Explain how humans have affected the carbon cycle.

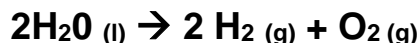
Humans have released increasing amount of carbon dioxide into the atmosphere which otherwise would have been contained in carbon form beneath layers of earth by burning fossil fuels. Humans have also decreased the number of plants and trees on the planet by using them for commercial uses or clearing large areas for development. These activities have caused unbalanced in carbon dioxide and oxygen seesaw and has resulted in increased carbon dioxide levels in the atmosphere and climate change.

4. List some of the most significant challenges engineers of the artificial leaf most overcome to make synthetic photosynthesis a mainstream energy source.

The chemical reactions inside an artificial leaf require catalysts. A major challenge is finding catalysts and materials that only produce the desired chemical products. Another challenge is the size of the leaf itself. In order for artificial leaf technology to become a mainstream reliable energy source it must be scaled up to produce an amount of energy comparable with other green energy sources which is proving to be a challenge for scientists.

Connecting Concepts

5. Compare and contrast oxidation and reduction and identify which element is being oxidized and reduced in the electrolysis of water equation shown below:



Oxidation is caused by the loss of electron(s) during a chemical reaction resulting in a positive oxidation state. Reduction is caused by the gain of electron(s) during a chemical reaction resulting in a negative oxidation state. In the electrolysis of water equation hydrogen is being reduced from a +1 oxidation state in water to a 0 oxidation state in hydrogen gas. Oxygen is being oxidized from a -2 oxidation state in water to a 0 oxidation state in oxygen gas.

6. Using the balanced chemical reaction for photosynthesis from question 1, prove mass (thus matter) was conserved during the chemical equation.



Answers may vary. Example:

Reactant side totals: 6 carbons x 12 g = 72 grams

18 oxygen x 16 g = 288 grams

12 hydrogen x 1 g = 12 grams

Total = 372 grams

Product side totals: 6 carbons x 12 g = 72 grams

18 oxygen x 16 g = 288 grams

12 hydrogen x 1 g = 12 grams

Total = 372 grams

Since the total mass is 372 grams on both sides of the equation, mass is conserved.

7. All plants and trees start as tiny seedlings; over time they grow to their mature form. For example, the primary source of mass in a tree is from carbon. What is the source of the carbon that allows a tree to grow?

The source of carbon is from the carbon dioxide in air. A common misconception is the mass of a tree comes from the dirt/soil.

8. What are some environmental advantages artificial leaf technology has over other sources of green energy such as ethanol fuel, wind, and solar?

Unlike ethanol fuel which requires large amount of energy, land, and even fossil fuels to produce, artificial leaf technologies are made from clean and sustainable resources. Artificial leaf technologies, due to their small size, do not leave a large footprint on the environment unlike solar panels and windmills which consume a significant amount of land or rooftops to produce energy.

9. The article mentions catalyst and their importance to both the natural and artificial photosynthesis process. What is a catalyst? How do catalysts increase the rate of a chemical process?

A catalyst is compound that speeds up a chemical process by lowering the activation energy required for a reaction to take place by providing an alternative mechanism for the reaction. Catalysts are also not consumed during the chemical process and leave the process ready to further catalyze future reactions.

Questions for Further Understanding and Exploration

10. The article states economists project the economic damages from climate change will reach \$1.7 trillion dollars per year by 2025 and roughly \$30 trillion per year by 2075. In detail, explain how global climate change can cause economic (financial) damage.

Climate change, particularly an increased global temperature, can result in more frequent natural disasters such as tornados, flooding, and hurricanes which are capable of catastrophic damage. Climate change can also impact crop yields, affect animal and insect populations, increased energy consumption due to the increased use of heating and air conditioning units due to more extreme temperatures (which also results in more pollution)

11. Artificial leaf technology has the potential to deliver a large amount of clean, sustainable energy with a small environmental footprint. Today is common to see solar panels and windmills in various parts of the country. Some people may argue that solar panels and windmills are not aesthetically pleasing. Propose a method to incorporate artificial leaf technology into the environment in an aesthetically pleasing manner. Create a model or diagram to support your answer.

Answers will vary. Student answers must include a diagram or model (visual component)

12. You are hired as marketing VIP for a leading artificial leaf technology start up company. Your task is to create a 30 second TV commercial to promote your product and encourage consumers to purchase and artificial leaf system for their property to power their home. You have control over the design of the leaf system and how residents may incorporate it onto their property. Use your smartphone to record the commercial and share your finish product with your teacher.

Answers will vary. Student commercials may be completed individually or in groups. The commercials should include a prototype, visuals, company name, and be energetic and fun!

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

Lessons and lesson plans

The Downside of Catalysts: Catalyst lesson plan. In this lesson students will make observations of a colorful homogenous catalyst and intermediate in a reaction demonstration that will spark their interests.

<https://teachchemistry.org/classroom-resources/the-downside-to-catalysts>

Exploring Automotive Corrosion: Electrochemistry Lesson plan. In this lesson students will investigate the galvanic corrosion that can occur when different metals come in contact with each other in modern cars.

<https://teachchemistry.org/classroom-resources/exploring-automotive-corrosion>

Color Solar Power: Solar Power Lesson plan. In this lesson students will make a dye-sensitized solar cell (also known as DSC or Gratzel cell) using extracts from produce.

<https://teachchemistry.org/classroom-resources/color-solar-power>

Other resources

Green Chemistry: Webinar. Annette Sebuyira shares her experience using green chemistry as a platform to teach core chemistry concepts, in a way that inspires students to seek solutions to real-world environmental challenges.

<https://teachchemistry.org/professional-development/webinars/green-chemistry>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Chemical change
- Electrochemistry
- Catalysts
- Intramolecular forces

Correlations to Next Generation Science Standards

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

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

HS-ETS1-3.

Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraint, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- LS1.C: Organization for Matter and Energy Flow in Organisms
- PS1.A: Structure and Properties of Matter
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Structure and function
- Systems and system models
- Energy and matter

Science and Engineering Practices:

- Planning and carrying out investigations

Nature of Science:

- Science investigations use a variety of methods
- Scientific knowledge assumes an order and consistency in natural systems.

Correlations to Common Core State Standards

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students what they know about photosynthesis and how it relates to climate change. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
 - As they read, students can find information to confirm or refute their original ideas.
 - After they read, ask students what they learned about artificial leaf technology and how it could help fight climate change.
- After reading and discussing the article, consider sharing the ACS Reactions video “What If Humans Could Photosynthesize?” (4:04) at <https://youtu.be/z3RGwdJGzOo> to learn more about requirements and tradeoffs of photosynthesis.

About the Teacher's Guide

Teacher's Guide team editors Dusty Carroll, Scott Hawkins, Matt Perekupka, and Jennifer Smith created the Teacher's Guide article material. Susan Cooper prepared the anticipation, reading guides, and connections to standards.

Christine Suh (Managing Editor) coordinated the production and development of the Teacher's Guides.

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