Atmospheric Pollution

Future of Agriculture Curriculum for Teaching Sustainability

Name: _____ Hour_____Date: _____

Date Packet is due:_____ Why late? _____Score: _____
Day of Week Date If your project was late, describe why

Overview: in this unit, you will investigate the molecular properties of some substances in order to explain how and why they have negative effects on atmospheric ecosystem services.

Main Questions

- In what ways can human activity affect ecosystem services provided by the earth's atmosphere?
- What are the molecular properties of some substances that are responsible for their impact on atmospheric ecosystem services?
- How does human activity relate to these substances and the disturbances that they cause?

Weekly Schedule

Monday:
- Data Dive – GHGs and Temperature

Tuesday:
- Nutshell Video & Notes
- Class discussion & revisions of explanations
- Optional: Greenhouse Effect Reading

Wednesday:
- Option A: PhET Greenhouse Effect Simulation
- Option B: Tabletop Climate Change

Thursday:
- Review & Assessment

Friday:
- Weekly Reflection
- Career & Community Connections

Semester Schedule

Week 0: Introduction & Lab Safety

Atoms to Ecosystems

Week 1: Matter & Energy
Week 2: Cell Biology
Week 3: Biodiversity & Ecosystems
Week 4: Biodiversity & Habitats Lab
Week 5: Midterm Assessments

Causes of Extinction

Week 6: Extinction
Week 7: Habitat Loss
Week 8: Invasive Species
Week 9: Land & Water Pollution
Week 10: Atmospheric Pollution
Week 11: Overharvesting
Week 12: Midterm Assessments

Sustainable Societies

Week 13: Natural Resources Management
Week 14: Societies & Sustainability
Week 15: Individual Sustainability
Week 16: Personal Campaigns
Week 17: Personal Campaigns

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National Science Foundation WHERE DISCOVERIES BEGIN
KBS LTER Kellogg Biological Station Long-term Ecological Research
MICHIGAN STATE UNIVERSITY

Day 1: Data Dive

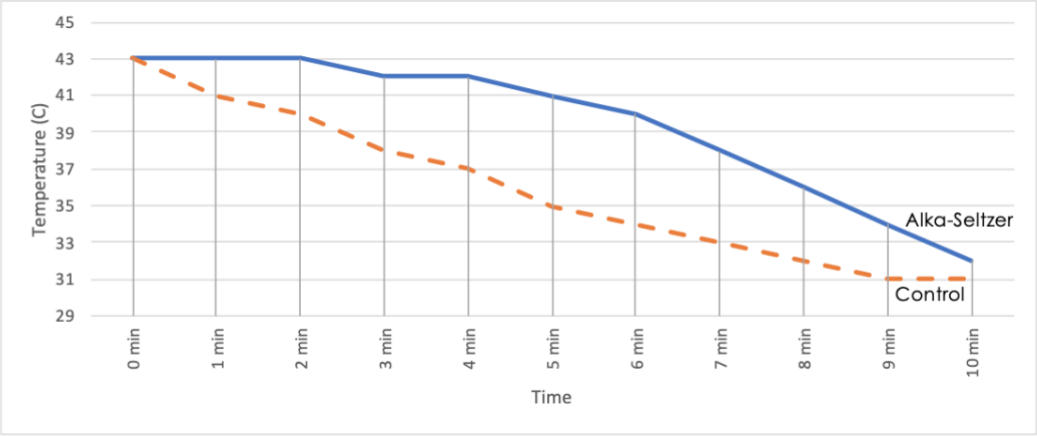
Intro Video: https://www.youtube.com/watch?v=213YJpNLBdg

Overview: In this activity, your group will review data in order to identify patterns and trends that you will use to develop an explanatory model. You will then compare your observations and explanations to those of other groups in order to check your accuracy and refine your explanatory model.

Directions: look at the data provided below in the two scenarios below. Then use this data to answer the accompanying questions. If you are unsure about how to interpret the data, work with your group and seek help from your instructor if necessary. Your instructor will decide if you should record your answers using scratch paper, a dry erase board, a digital document, or another option.

Scenario 1: A group of high school students are conducting an experiment to see how *greenhouse gases* (such as carbon dioxide) interact with heat energy. They acquire two bioreactor chambers (*see picture* →). These are sealed beakers that have a built-in thermometer and heater. They will increase the concentration of carbon dioxide inside one of the chambers using Alka-Seltzer (a treatment for indigestion that releases CO_2 as it interacts with water). The students add 400 ml of tap water to each container. They add an Alka-Seltzer tablet to one bioreactor, which fizzes and releases CO_2 (most of which remains in the air inside the chamber). They then turn on the built-in heaters and warm each chamber so that the water and the air above it within the chamber is heated to 43° Celsius. They position the thermometers so that they are measuring the temperature of the air. They then turn off the heaters. They record the temperature in each bioreactor every minute. Their data is shown below.

Time	Alka-Seltzer	Control
0 min	43	43
1 min	43	41
2 min	43	40
3 min	42	38
4 min	42	37
5 min	41	35
6 min	40	34
7 min	38	33
8 min	36	32
9 min	34	31
10 min	32	31



Source: Waterford Agricultural Sciences (www.wuhsag.weebly.com)

1. What is a conclusion that would be supported by this data?
    a. How is this conclusion supported by this data?
    b. What specifically suggests that your claim is accurate?

2. What is a second conclusion that would be supported by this data?
    a. How is this conclusion supported by this data?
    b. What specifically suggests that your claim is accurate?

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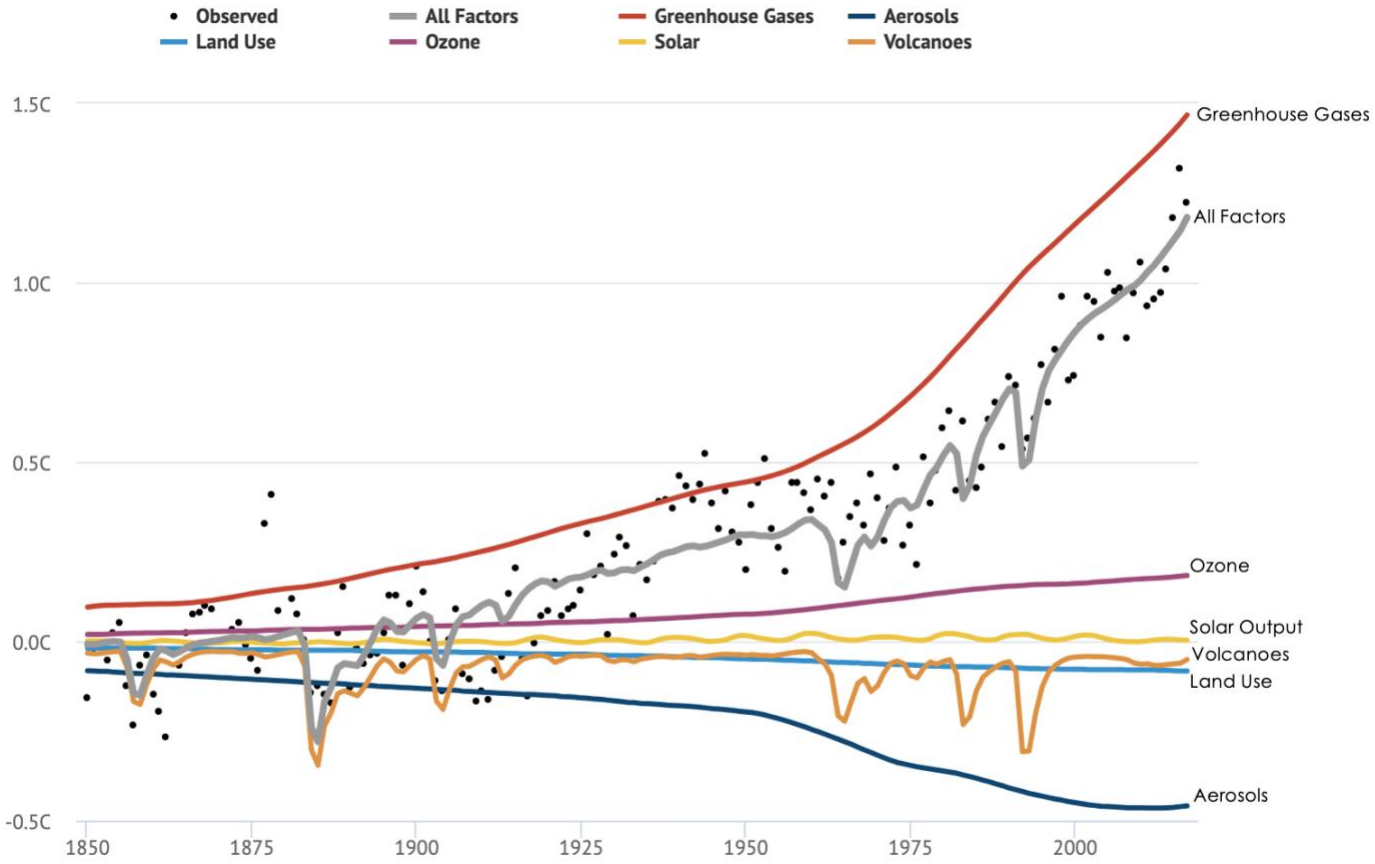
Scenario 2: A group of scientists have observed changes to the mean (average) surface temperatures of the planet since the mid-1800s. This is indicated in the graph below as a series of dots. These scientists are interested in what factors might be responsible for these changes in temperature. They identify six possible causes for these shifts in temperature: changes to land use (such as deforestation), changes in levels of atmospheric ozone, changes in levels of atmospheric greenhouse gases, solar energy output, prevalence of aerosols, and volcanic activity. They then calculate how changes to these factors would influence the earth's temperature over time. They show this on the graph below.

Source: *www.carbonbrief.org*



3. What trends do you notice in temperature between 1850 and today?

4. What is a conclusion that would be supported by this data?
    a. How is this conclusion supported by this data?
    b. What specifically suggests that your claim is accurate?

5. What is a second conclusion that would be supported by this data?
    c. How is this conclusion supported by this data?
    d. What specifically suggests that your claim is accurate?

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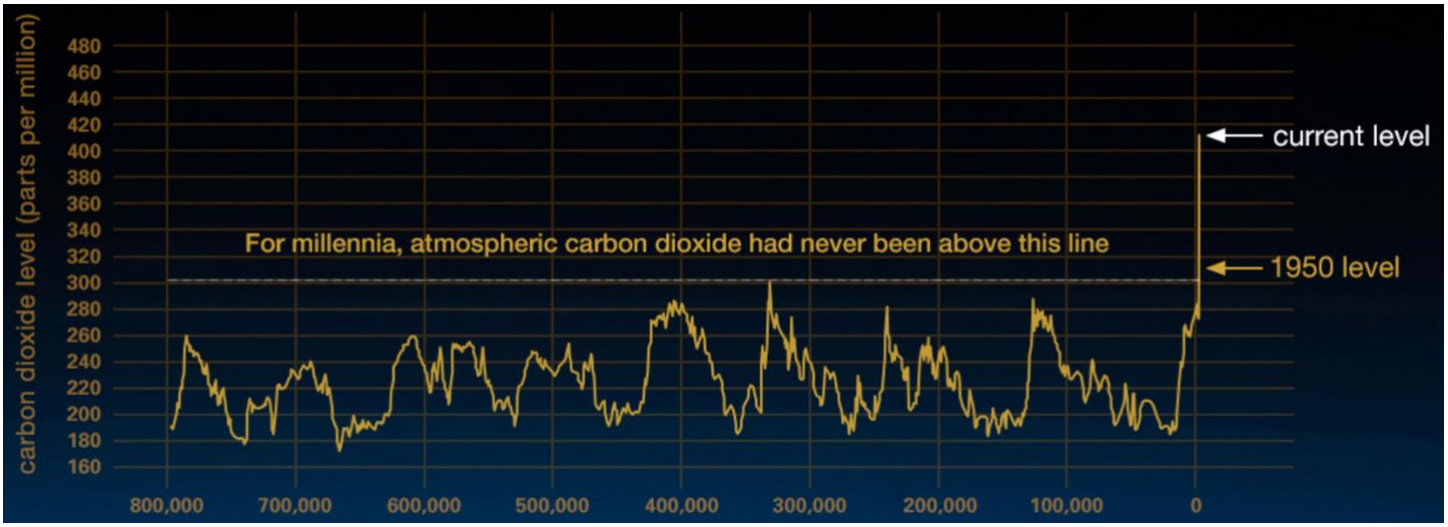
6. Based on the data on the previous two graphs, create a **hypothesis** that summarizes the relationship between temperature and greenhouse gases like carbon dioxide.

   I hypothesize that _____

   _____

   I think that this hypothesis is accurate because _____

   _____



Source: https://climate.nasa.gov/evidence/

7. As sheets of ice form, they trap air in tiny bubbles. This air remains unchanged inside the ice, preserving a record of the atmospheric conditions over periods as long as hundreds of thousands of years. Scientists have measured the preserved carbon dioxide concentrations in these air bubbles. This graph from NASA (above) shows fluctuations in the earth's average atmospheric carbon dioxide levels over the previous 800,000 years based on this data.

   What was the highest level of CO2 prior to the Industrial Revolution 150 years ago? _____ ppm

   What is the current level of atmospheric CO2? _____ ppm

8. What might be one possible explanation for why CO2 is so much higher now than compared to any other point in the existence of human beings?

9. Based on your hypothesis about the relationship between greenhouse gases like CO_2 and temperature, why might it be a problem that atmospheric carbon dioxide is at an unusually high level?

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Day 2: Notes & Discussion

Introduction & Directions: In this activity, you will begin by watching a short video about atmospheric pollution. This will help to clarify some of the questions you may have had yesterday. After the video, you will look at a short slideshow presentation that will provide you with specific information about this topic. Your instructor may decide to deliver the presentation as a classroom lecture or they may allow you to read the notes individually or in small groups (depending on your previous experience and capabilities with this content). You will work in small teams to answer the questions listed below and on the slides. You should take notes in a notebook, on a dry erase board, or on scratch paper so that you are prepared to deliver your responses during the class discussion that will follow. *Note: your instructor may assign your group to answer specific questions if time is limited.*

URL Links
YouTube Video: https://www.youtube.com/watch?v=HbpWutR67vE
Also consider: https://www.youtube.com/watch?v=sTvqIijqvTg&feature=youtu.be

Slideshow Presentation: https://www.factsnsf.org/uploads/1/4/0/9/14095127/2020-10-1_facts-nr_atm_pollution_w_questions.pdf (or visit www.factsnsf.org and use the menu bar).

Discussion Questions:

1. Summarize how the atmosphere makes life possible on earth. Provide descriptions of specific examples (such as those related to precipitation, temperature, oxygen, nitrogen, carbon, and ozone).
2. Atmospheric pollution consists of excessive levels of a specific chemical or particle in the atmosphere that disrupts ecosystem function and services. As a group, explain how the hole in the ozone layer, acid rain, and climate change reflect each aspect of this definition.
3. The problems from CFCs and acid rain are far less prevalent today. Why? How were these problems minimized?
4. What is a *greenhouse gas*? What is the *greenhouse effect*? How do greenhouse gases affect the earth's surface temperatures?
5. What molecular properties are needed for something to be a greenhouse gas?
6. Why are CO_2 levels rising? What is the source of this additional CO_2?
7. How do rising CO_2 levels affect precipitation? How could an increase in atmospheric CO_2 levels cause both more droughts *and* more flooding?
8. Couldn't the changes we are experiencing just be a natural cycle? How do we know that humans are responsible for these changes?
9. How can we reduce levels of atmospheric carbon dioxide? Use the terms *photosynthesis*, *biomass*, and *carbon sequestration* in your response.
10. Will the CO2 in the atmosphere ever just 'go away'? What happens if we don't do anything?
11. How could the economic solution for acid rain be helpful in addressing excess atmospheric CO_2?
12. How do the carbon dioxide emissions from American lifestyles compare to those of other similar nations? What does this suggest about our capacity for reducing our own individual CO_2 emissions?

Be sure to revisit your explanations from the previous day's activity and add details or corrections as needed.

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Day 3 – Option A: PhET Greenhouse Gas Simulation

Originally developed for Carbon TIME. Used with permission.

See the directions in The Greenhouse Effect Simulation Directions (*see appendix*) to complete this worksheet.

A. Investigating how different gases in the atmosphere interact with light:

1. Observe how the infrared and visible light photons respond when they encounter CO2 and N2 molecule. Then circle the descriptor that best describes the movement of each kind of photon when it strikes each kind of gas molecule below:

When a visible light photon hits CO_2, the photon's movement is… **Unchanged** **Scattered**

When an infrared photon hits CO_2, the photon's movement is… **Unchanged** **Scattered**

When a visible light photon hits N_2, the photon's movement is… **Unchanged** **Scattered**

When an infrared photon hits N_2, the photon's movement is… **Unchanged** **Scattered**

2. How did the interactions of CO2 and infrared photons differ from the interactions of N2 and infrared photons?

3. How can the different molecular properties of CO_2 and of N_2 help to explain these differences? (Revisit the accompanying reading if you need to).

4. How do these molecular properties determine whether or not an atmospheric molecule can be a greenhouse gas? (Revisit the accompanying reading if you need to).

5. How do your observations in this exercise relate to the Greenhouse Effect? Revisit the definition in the reading if needed.

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B. Investigating how different gases in the atmosphere affect the Earth's temperature:

6. Complete the table below to record your observations from this activity:

	Impact on Yellow Light Photons	Impact on Red Infrared Photons	Temperature Range
Low GHG's			
High GHG's			

7. In what ways (if any) did the movement of the yellow visible light photons change as the greenhouse gas concentrations were increased?

8. In what ways (if any) did the movement of the red infrared photons change as the greenhouse gas concentrations were increased?

9. How do your observations in this exercise relate to the Greenhouse Effect? Revisit the definition in the reading if needed.

10. What happened to the temperature as the concentrations of greenhouse gases were increased?

11. What is the relationship between the concentration of greenhouse gases in the atmosphere and the temperature of the earth's surface?

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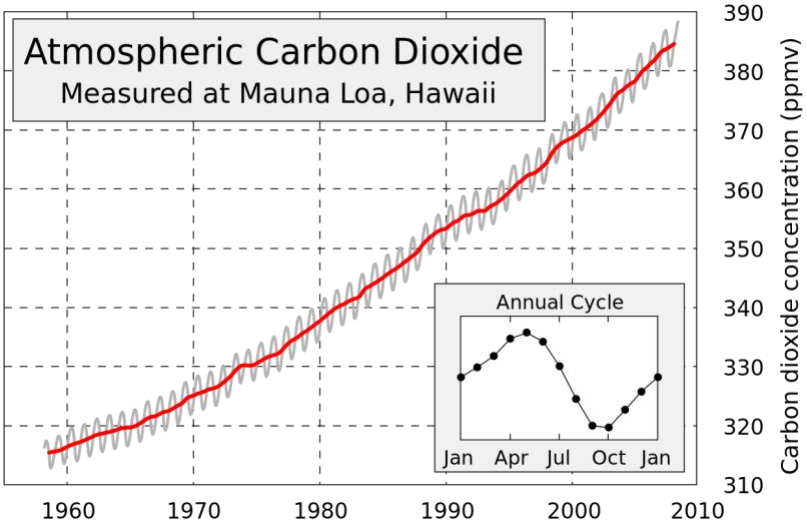
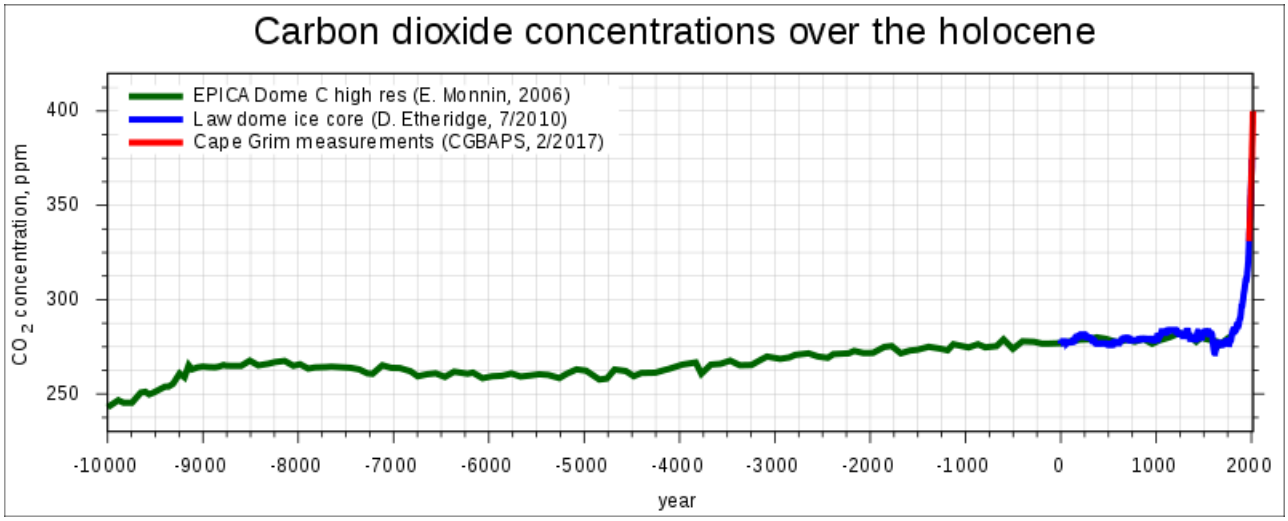
C. Investigating why the Keeling Curve is important:

12. How do the patterns and relationships that you observed throughout this activity relate to the Keeling Curve (below)?



13. Given what you have observed throughout this activity in regard to the relationship between CO_2, infrared radiation, and temperature, respond to the graph below showing the changes to CO_2 concentrations since the end of the last ice age. What implications could these trends have for the future of the planet given the current trajectory of CO_2 concentrations?



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Day 3 – Option B: Tabletop GH Effect

Overview: You will measure the effects of carbon dioxide concentrations on temperature in a lab setting.

Tabletop Climate Change Directions: in this activity, your class will compare the thermal properties of normal air to air with higher concentrations of CO_2. Sealed vessels with cool water will be heated until the temperature rises to 45 degrees C. The heat is then turned off and the air allowed to cool naturally. Temperature readings are taken at definite time intervals and plotted on graph paper. The results will demonstrate the effects of increased CO_2 on the rate of heat loss from air.

1. In a moment, you will be comparing the rate of cooling from a flask with 350-400 ppm of CO_2 to a flask with much higher levels of CO_2. What do you expect will happen when the heaters are switched off?

   We hypothesize that _____

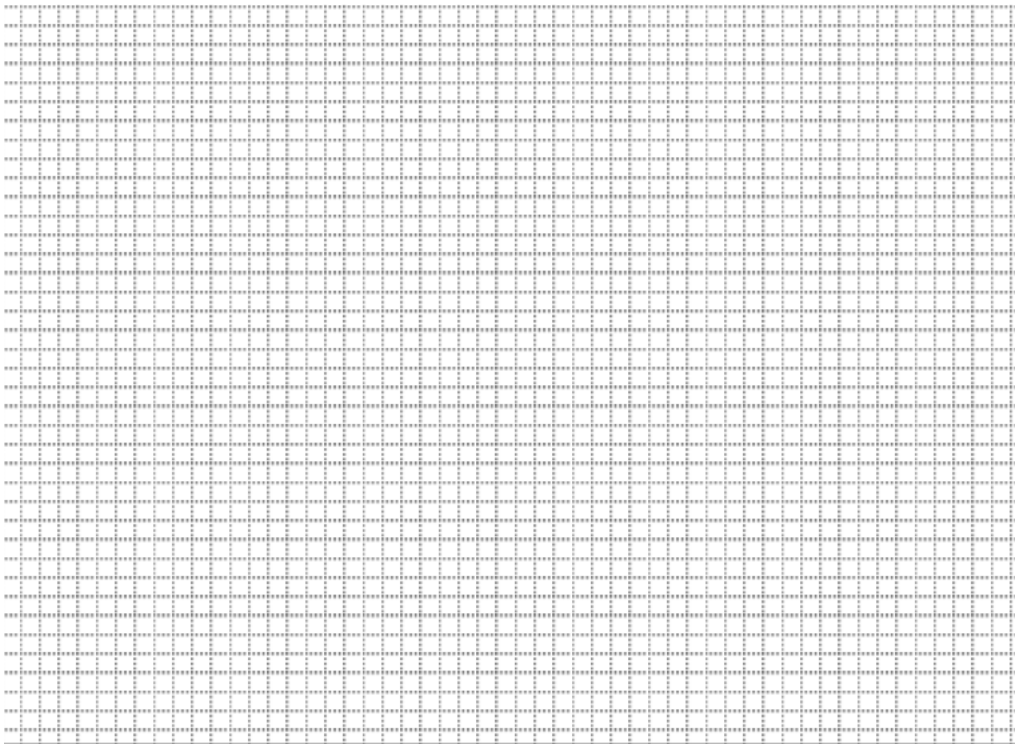
   _____

   We think this because _____

   _____

2. Complete the table below and graph the results on the right:

Record Temp (C) Below		
	Alka-Seltzer	Control
Initial Temp		
0 minute		
1 minute		
5 minute		
10 minute		
15 minute		
20 minute		
25 minute		
30 minute		



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3. Did the results of this experiment support your hypothesis? _____ Explain: _____

4. How do the molecular properties of CO_2 enable it to slow the loss of heat from this container?

5. In the space below, create a drawing of how the molecules of CO_2 are interacting with the heat energy inside of this container. Use arrows to show the movement of heat energy:

6. In 2010, more than 30 million metric tons of CO_2 was emitted because of human activity. What impact would an annual addition of 30 million tons of CO_2 have on the atmosphere's heat retaining properties?

7. What are some personal activities of yours that would result in large amounts of CO_2 being emitted? List and describe 3 possible examples below:

1. _____

2. _____

3. _____

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Day 4: Review & Assessment

Directions: you will begin by reviewing the unit objectives in your small groups. For each objective, rank it as a 1 (*completely unsure*), 2 (*somewhat unsure*), or 3 (*completely sure*) based on your comfort with that objective. After a few minutes of review, your instructor will lead a whole-class review. This is your chance to ask any questions you still might have about the concepts in this unit. Begin with anything you ranked as a "1".

After you have completed the unit review, you will be taking an individual multiple choice quiz and/or a group short answer quiz. These quizzes may be graded in class to help you better understand the question and the correct answer.

Unit Objectives:

1. Summarize how the atmosphere makes life possible on earth. Provide descriptions of specific examples (such as those related to precipitation, temperature, oxygen, nitrogen, carbon, and ozone).
2. Atmospheric pollution consists of excessive levels of a specific chemical or particle in the atmosphere that disrupts ecosystem function and services. As a group, explain how the hole in the ozone layer, acid rain, and climate change reflect this definition.
3. The problems from CFCs and acid rain are far less prevalent today. Why? How were these problems minimized?
4. What is a *greenhouse gas*? What is the *greenhouse effect*? How do greenhouse gases affect the earth's surface temperatures?
5. What molecular properties are needed for something to be a greenhouse gas?
6. Why are CO_2 levels rising? What is the source of this additional CO_2?
7. How do rising CO_2 levels affect precipitation? How could an increase in atmospheric CO_2 levels cause both more droughts *and* more flooding?
8. Couldn't the changes we are experiencing just be a natural cycle? How do we know that humans are responsible for these changes?
9. How can we reduce levels of atmospheric carbon dioxide? Use the terms *photosynthesis, biomass,* and *carbon sequestration* in your response.
10. Will the CO2 in the atmosphere ever just 'go away'? What happens if we don't do anything?
11. How could the economic solution for acid rain be helpful in addressing excess atmospheric CO2?
12. How do the carbon dioxide emissions from American lifestyles compare to those of other similar nations? What does this suggest about our capacity for reducing our own individual CO2 emissions?

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Day 5: Career Connections

Directions: to begin this activity, you will form small groups (ideally, 3-4 individuals). These groups could either be your assigned lab groups from this week OR you could find 2-3 other individuals who have career interests that are similar to yours. Your instructor will inform you which option you will be using to form your groups.

Once you have formed your groups, address the following questions as a team.

1. Try to summarize everything that you have learned so far in this course within your group. Try to identify the common themes, major ideas, and most important concepts from the content you have learned.

2. Try to get a sense of how each person in the group feels about these concepts. Is there anything that anyone still doesn't completely understand? Is there anything that anyone maybe disputes or disagrees with? Is there anything that seemed particularly surprising or noteworthy to anyone?

3. Using a notebook, whiteboard, or scratch paper, list what you think are the most important ideas and concepts that you have learned so far. Aim to have at least 5 or 6 ideas written down. It is ok to have more than this.

4. As a group, try to determine how these ideas relate to the careers you intend to go into. Specifically…
   a. How might your daily activities in this future career be affected by these concepts?
   b. How might the decisions you make as part of this career be influenced by these ideas?
   c. How has your intended career area changed over time as a result of our understanding of these concepts? How might it continue to change in the future?

5. Atmospheric pollution can greatly reduce biodiversity in affected areas, decreasing the ecosystem services and resiliency of those regions.
   a. How do you think your career might currently *increase* the risk of atmospheric pollution and *decrease* the biodiversity of an area?
   b. How do you think your career could be improved so that it might *decrease* the risk of atmospheric pollution and *increase* the biodiversity of an area?

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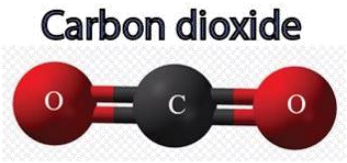
Atmospheric Pollution Individual Quiz

Name: _____ Hour_____ Date:_____ Score:_____ /___

Directions: This quiz should be completed on an individual basis. A 3x5 notecard with handwritten notes can be used on this quiz.

1. **This is a molecule of carbon dioxide. If we increase concentrations of this molecule in the atmosphere, which of the following would occur?**



   a. The atmosphere will do more to protect living species because CO_2 forms a barrier that protects living organisms from UV rays.
   b. We can expect warmer surface temperatures because CO_2 molecules absorb and scatter infrared radiation.
   c. The atmosphere will not change in any significant way because molecules like CO_2 only comprise 0.04% of the atmosphere.
   d. Continued increases to carbon dioxide levels would be helpful as this is a naturally occurring gas that is necessary for life on earth and cannot be a pollutant.

2. **Please briefly explain why each option is correct or incorrect.**

   a. _____

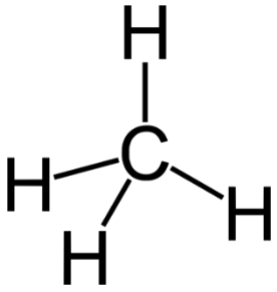
   b. _____

   c. _____

   d. _____

3. **CO2 is a greenhouse gas. What does this mean?**
   a. CO_2 is necessary for plant growth; because plants are grown in a greenhouse, we call CO_2 a greenhouse gas.
   b. CO_2 is released by plants and will accumulate in an enclosed area with plants (like a greenhouse).
   c. CO_2 is what enables a greenhouse to stay warm without an additional source of heat.
   d. CO_2 allows light energy to reach the surface of the earth but slows the loss of heat (similar to the function of a greenhouse) by absorbing and scattering infrared radiation.

4. **This is a molecule of methane. It consists of one carbon atom and four hydrogen atoms. Would increasing the levels of methane in the atmosphere affect the earth's surface temperatures?**



   a. Yes – methane is a greenhouse gas based on its molecular properties.
   b. No – methane cannot retain heat because it is a gas.
   c. Yes – methane must retain heat because all gases retain heat.
   d. No – methane cannot retain heat because it does not contain oxygen.

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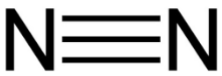
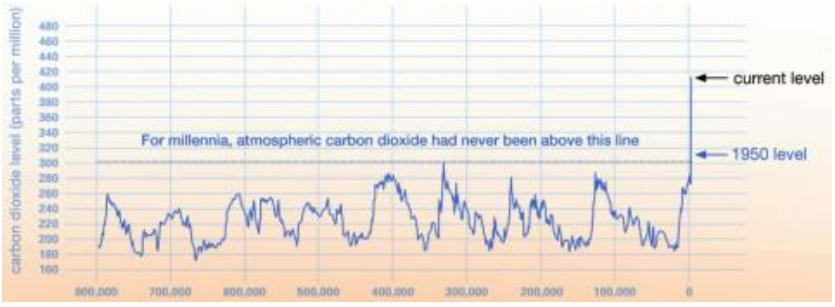
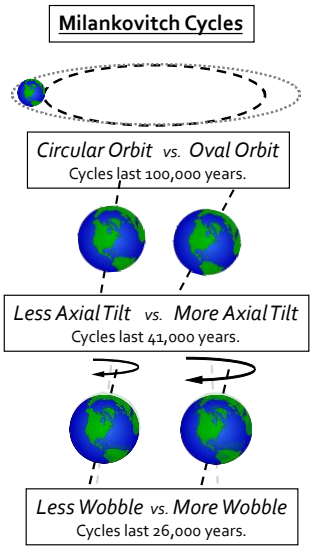
5. **This is a molecule of nitrogen gas. It consists of two nitrogen atoms bonded together. Would increasing the levels of nitrogen gas in the atmosphere affect the earth's surface temperatures?**
    a. Yes – nitrogen is the most prevalent gas in the atmosphere.
    b. No – nitrogen cannot retain heat because it is a gas.
    c. Yes – nitrogen must retain heat because all gases retain heat.
    d. No – nitrogen does not retain heat because of its molecular properties.



6. **Which of the following would be effective solutions for reducing atmospheric CO_2 levels?**
    a. Increasing the rate of photosynthesis.
    b. Slowing or stopping the combustion of fossil fuels.
    c. Reducing rates of decomposition through carbon sequestration.
    d. All of the above
    e. None of the above.





Use the images shown here to assist you in answering the question below.

7. **True or False: it is likely that the changes we're seeing currently regarding carbon dioxide levels and climate are part of a natural cycle.**
    a. True: we have evidence that similar events have occurred many times in the history of human beings, and they occurred at the same pace and to the same extent as what we're seeing today.
    b. False: the climate normally does not change, and so any changes to climate are unnatural.
    c. True: these changes are likely due to the Milankovitch Cycles (or changes to the earth's orbit and tilt); these cycles last a few decades or centuries, so we're due for changes.
    d. False: CO_2 levels have never risen this high or this quickly in the history of humans as a species, and natural cycles (like Milankovitch Cycles) take tens of thousands of years to occur.

8. **How might increasing levels of carbon dioxide affect agriculture?**
    a. Increasing CO_2 levels makes precipitation less frequent, which could impair crop growth.
    b. Increasing CO_2 levels worsens the rates of droughts and flooding and reduce crop yields.
    c. CO_2 causes changes to the climate that reduce biodiversity and impair ecosystem services. Because agriculture depends on biodiversity and ecosystem services, production of food would suffer as a result.
    d. All of the above.
    e. None of the above.

9. **What are three realistic choices that you could make to reduce your own CO_2 emissions?**

1. _____

2. _____

3. _____

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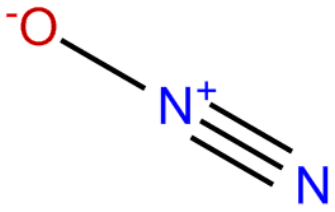
Atmospheric Pollution Group Quiz

Names: _____

_____ Hour_____ Date:_____ Score:_____ /

Directions: This quiz should be completed in small assigned groups. You can use your notes. Each question should be completed by a different individual. All students should contribute to developing each answer. Those who are unable to do so may be asked to complete this quiz individually.

1. This is Nitrous Oxide. If we increase levels of N_2O in the atmosphere of Planet X by 50%, what would happen to temperature of that planet's atmosphere? Please explain & justify w/ evidence. Use the following terms: *greenhouse gas; molecular properties; elements; greenhouse effect; infrared radiation*.



_____

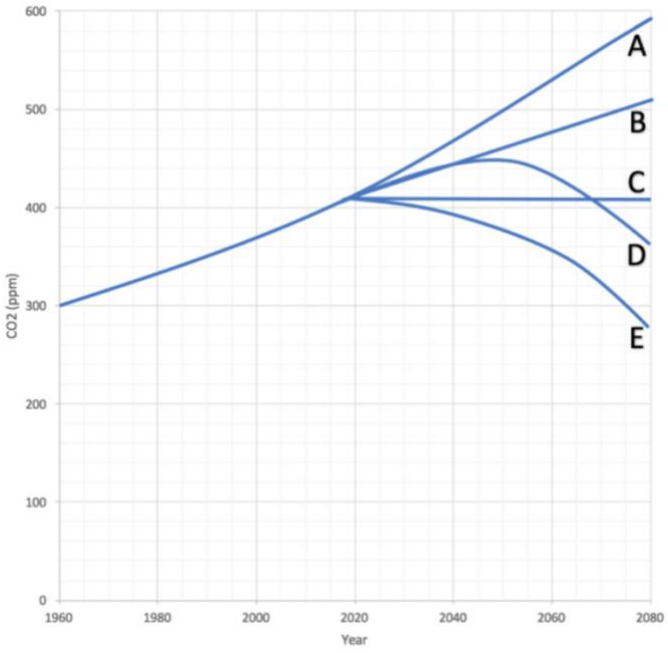
_____

_____

_____

_____

2. If we were to cut global fossil fuel use by 50% this year and keep our usage at this specific level permanently, what would happen to CO_2 levels in the atmosphere? Choose one of the options (A, B, C, D, or E) and justify your choice with evidence about what you know about CO_2.



We chose *because* _____

_____

_____

_____

_____

_____

_____

_____

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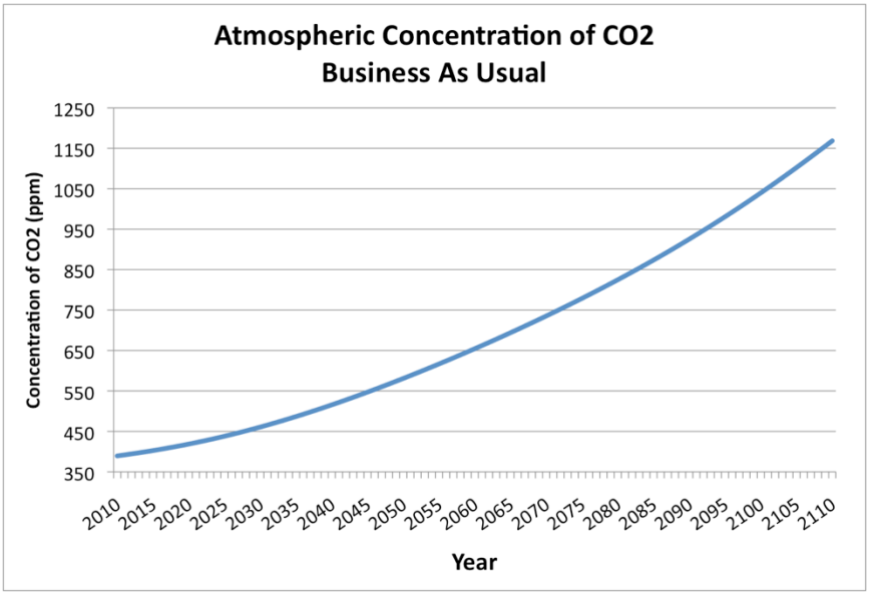
3. The graph on the right shows how CO_2 levels will change over the next 100 years under a "business as usual" scenario (i.e. no changes to the current trends related to our CO_2 emissions).



This projection indicates that by 2050, CO_2 levels would be near 600 ppm. This concentration of CO_2 is roughly twice as high as the previous natural maximum of CO_2 that has occurred in the time that humans have existed on the planet.

What are some outcomes that we would expect if CO_2 levels were to continue to increase at this rate? In your response, explain a) what we know about the molecular properties of CO_2, b) the relationship between CO_2 and temperature, and c) how rising levels of CO_2 affect ecosystem function, ecosystem services, and human activity.

4. Couldn't the changes that are now happening in the climate just be part of another natural cycle? Explain using evidence and reasoning.

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5. Given our experiences with other forms of air pollution (such as acid rain and CFCs), can we do anything about this problem? What specifically needs to occur in order for this problem to be fixed? Propose multiple solutions; justify these choices with evidence and reasoning.

6. A friend of yours argues that high CO_2 emissions are just the price we have to pay for living in a modern society. They maintain that while this may be bad for the planet, so is pretty much everything else we do. If we want to fix climate change, they argue that we'll need to give up our modern lifestyles and live like we're in the stone age. Is this accurate? Explain.

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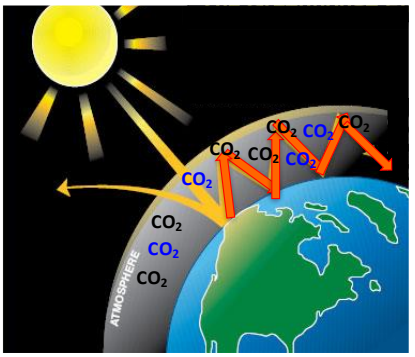
Optional: Greenhouse Effect Reading

Note: These materials are take from Carbon TIME (used with permission). Written by C. Kohn

The Greenhouse Effect

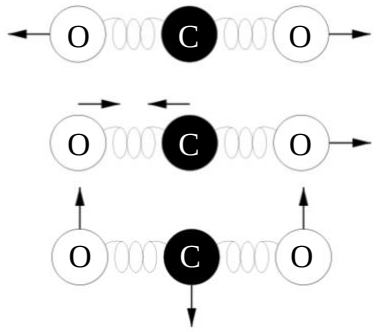


Just as the composition of your clothing affects the movement of heat energy away from your body into the surrounding air, the composition of the atmosphere affects how the temperature of the earth is regulated. The temperature of our air depends on the balance between solar radiation (mostly visible light) that warms the Earth up and invisible infrared (IR) radiation that cools the Earth down if it leaves the Earth and goes into outer space. The gases in the atmosphere mostly let solar radiation pass right through, but the story about how they interact with infrared radiation is more complicated—and that's a story we need to tell.

Greenhouse Gases

Most of the atmosphere is comprised of nitrogen gas (N_2) and oxygen gas (O_2), but these gases do not change the rate at which energy moves from the surface of the earth into space. On the other hand, some gases like carbon dioxide (CO_2) affect how energy (in the form of infrared radiation) is able to move from the earth's surface into space. These kinds of gases are called *greenhouse gases* because like a greenhouse or a car on a hot summer day, they allow visible light radiation to enter, but slow the loss of leaving infrared radiation.

So why do some gases slow the loss of heat in the atmosphere while others don't? Some molecules absorb infrared light by converting the light energy into the energy of vibration. Molecules with more than two atoms, and those with different kinds of atoms can vibrate in multiple kinds of ways, allowing them to absorb and re-emit infrared radiation. Whether or not a molecule can interact with infrared radiation leaving the Earth depends on these vibrations. The atoms on N_2 and O_2 molecules are identical and can only move closer or further apart. This is not complex enough to enable interaction with infrared radiation. On the other hand, there are multiple kinds of atoms on a CO_2 molecule, and they have complex vibrational modes. This allows CO_2 to absorb infrared light and emit it in any direction. This slows the loss of this energy from the earth's atmosphere. Increasing the levels of greenhouse gases that exist in the atmosphere makes it more difficult for infrared radiation to leave the earth (similar to the effect of slowly closing car windows on a sunny day).

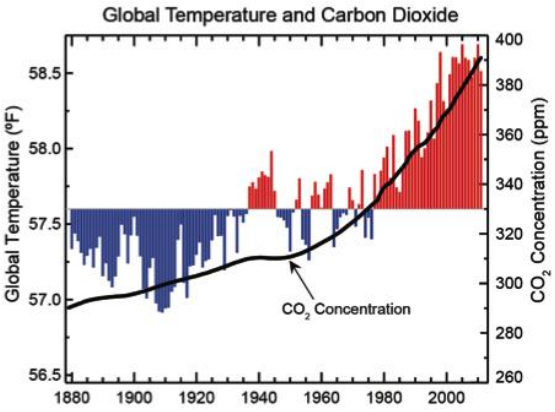


The atoms on a CO2 molecule have more complex vibration modes that allow them to absorb infrared light and emit it in any direction. (*Source: scied.ucar.edu*)

Connecting the Keeling Curve to the Greenhouse Effect

This naturally-occurring phenomenon is called the *greenhouse effect* and is necessary for life on Earth. Without greenhouse gases, the Earth would be freezing cold! However, if the concentration of greenhouse gases in the atmosphere increases *too much*, it will cause the planet to reach temperatures that damage our ecosystems. Just like leaving a car's windows closed on a hot summer day can cause the temperature inside the car to rise, increasing the concentration of CO_2 and other greenhouse gases in the atmosphere can cause the temperature of the planet to increase.

Dr. Charles Keeling was the first person in the world to accurately determine the rate at which carbon dioxide in the air was gradually increasing each year. Greater concentrations of CO_2 result in greater absorption of infrared radiation. As a result, the average temperature of the Earth is increasing. There are still hot places and cold places, and there are still hot days and cold days, but as the graphs shows, the Earth's overall average temperature has been increasing for more than 100 years.



Source: 2013 Draft National Climate Assessment

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Appendix: Data Dives / Case Studies

Overview: Data Dives and Case Studies are exercises in which students are presented with data from experiments or scenarios, and are asked to identify trends and develop explanatory models in a process that is very similar to what actual scientists do on a regular basis.

Directions: Students should consider the data or scenario in their assigned groups. They should work with their group members to make sense of the information provided and try to determine the conclusions that can be drawn from it. Students may struggle with this, especially in their first attempts and particularly if your students have limited experience reading graphs and data tables. It may be necessary for you to project the data onto a large screen and guide students by explaining the steps that you would use to make sense of what is being reported. This may be difficult; just like explaining the steps of tying your shoes can be challenging because you rarely have to think about it, it can be exceptionally challenging for someone who is scientifically literate to identify the thought processes that they use to make sense of data. It may be helpful to jot down your ideas in advance and have them ready prior to the start of this class.

Students are likely to struggle to varying extents. That is ok! Be sure to float from group to group to assist. Be sure to remind group members to help each other out. It might ideal to assign groups with a mix of abilities. Encouraging struggling students to work with their better-prepared peers, and conversely, encouraging high performing students to advance their abilities by working with individuals with different skill sets helps to prepare students for the kinds of situations they will encounter in their careers and personal lives. Plan to allow for about 15-20 minutes to introduce the activity and review how to interpret this information with your students. About a third to half of the class period should be reserved for allowing students to work in their individual groups. The remaining time should be reserved for intergroup or whole-class discussion so that students can engage in scientific debate and argumentation.

It would a good idea to remind students that the term *argumentation* is used differently between scientists and the general public. While argumentation generally has a negative connotation (such as a "heated argument"), argumentation among scientists is generally very good-natured and polite. The goal is not to "win" an argument but rather to expand the understanding of the phenomenon by all involved. Often scientists on opposing sides of an issue will both change their stance as a result of the improved understanding that results from engaging in argumentation. Similarly, students should not be trying to disprove each other or prove that they have the "right" answer. Rather, students should be examining the differences in their conclusions, the manner in which each conclusion was reached, and the similarities and agreements that exist among different conclusions.

Students may reach a conclusion that is not entirely supported by evidence. The temptation may be to point out errors in their reasoning. However, when students are struggling, they are also likely improving their abilities in evidence-based reasoning, which is one of the most important goals of this kind of instruction. Try to resist the urge to correct student errors; rather, try to probe their understanding and challenge them to re-examine the evidence to check the validity of their conclusions and the conclusions of other groups. Consider using the 9 Talk Moves (next page) to support productive classroom dialogue. Remember – students should re-visit their explanations and models repeatedly over the course the week. If they don't get it right on the first try, they will have more opportunities to do so.

Note: students could legitimately question some sources of this data as being potentially biased. While more reliable sources of data exist, their presentation of this data was less accessible to a high school audience. The data provided in this exercise align with that provided in peer reviewed sources from more reliable origins. We have chosen to utilize this source's data as a necessary compromise between accessibility and reliability.

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Goals for Productive Discussions and Nine Talk Moves

Goal: Individual students share, expand and clarify their own thinking

1. Time to Think:

Partner Talk

Writing as Think Time

Wait Time

2. Say More: "Can you say more about that?" "What do you mean by that?" "Can you give an example?"

3. So, Are You Saying…?:
"So, let me see if I've got what you're saying. Are you saying…?" (always leaving space for the original student to agree or disagree and say more)

Goal: Students listen carefully to one another

4. Who Can Rephrase or Repeat?

"Who can repeat what Javon just said or put it into their own words?" (After a partner talk) "What did your partner say?"

Goal: Students deepen their reasoning

5. Asking for Evidence or Reasoning:

"Why do you think that?" "What's your evidence?" "How did you arrive at that conclusion?" "Is there anything in the text that made you think that?"

6. Challenge or Counterexample:

"Does it always work that way?" "How does that idea square with Sonia's example?"
"What if it had been a copper cube instead?"

Goal: Students think with others

7. Agree/Disagree and Why?:

"Do you agree/disagree? (And why?)" "Are you saying the same thing as Jelya or something different, and if it's different, how is it different?" "What do people think about what Vannia said?"
"Does anyone want to respond to that idea?"

8. Add On:

"Who can add onto the idea that Jamal is building?"
"Can anyone take that suggestion and push it a little further?"

9. Explaining What Someone Else Means:

"Who can explain what Aisha means when she says that?" "Who thinks they could explain in their words why Simon came up with that answer?" "Why do you think he said that?"

Source: https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

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Appendix: PhET Greenhouse Effect Simulation

Note: These materials are take from Carbon TIME (used with permission)

Note: Digital or hard copies of these instructions should be provided to your students for this activity.

Introduction: The PhET Greenhouse Effect Simulation allows you to change the atmospheric greenhouse gas concentration, observe how these changes affect the movement of infrared photons into space, and determine how these interactions ultimately affect the temperature of the Earth's surface. Using the PhET Simulation, you will investigate three questions:

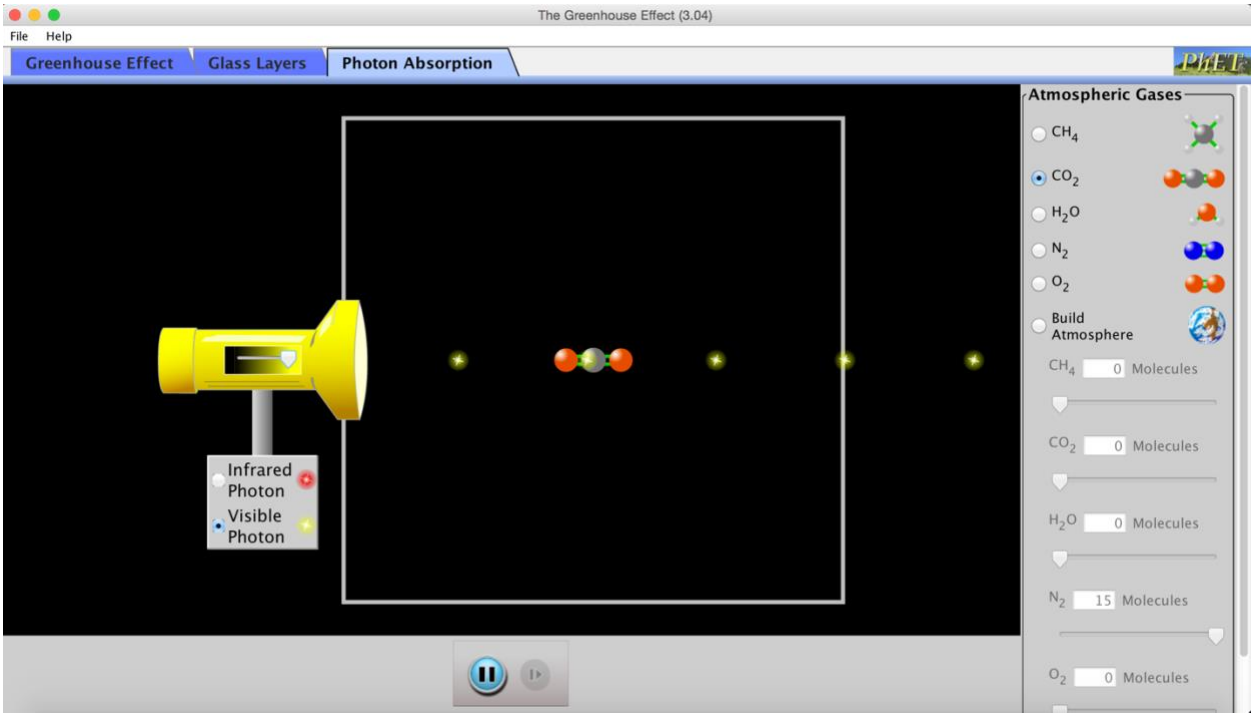
1. How do different gases in the atmosphere interact with light?
2. How do gases in the atmosphere affect the Earth's temperature?
3. Why is the Keeling Curve important?

Ordinarily, it would be impossible to directly observe the interactions of atmospheric gases with light. The PhET simulation serves as a model to make these interactions visible. This can help us explore patterns that are otherwise hard to see.

Downloading the PhET Simulation: you will need download it onto the computers or devices that your students will be using. For the file and for instructions on how to download, visit https://phet.colorado.edu/en/simulation/greenhouse .

A. Investigating how different gases in the atmosphere interact with light:

Open the PhET simulation. For the first questions, you will need to open the Photon Absorption Tab (in the upper left). Some gases are unable to interact with visible and/or infrared radiation. It just passes through the gas molecule unaffected. In other cases, a gas molecule may be able to absorb and re-emit a particular form of radiation (causing it to visibly 'wiggle' in this simulation). This component of the PhET simulation helps us to see which gases interact with each kind of radiation. You will be comparing two different gases in this simulation: CO_2 and N_2.



CO_2 and Light Photons: Under the "Atmospheric Gases" panel, select CO_2. On the "radiation gun" on the left-hand side of the screen, make sure that the "Visible Photon" option is selected. Move the slider on the gun all the way to the right and observe how the infrared photons respond when they encounter the CO_2 molecule. Record your data on your worksheet.

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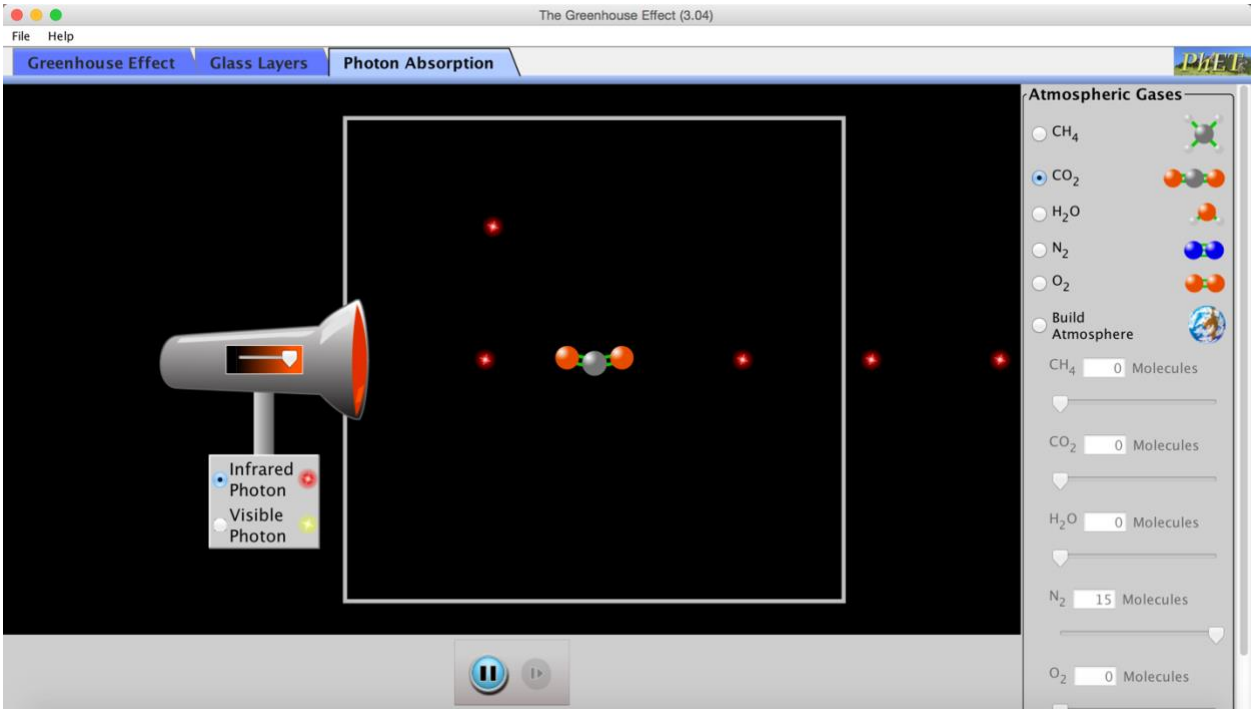
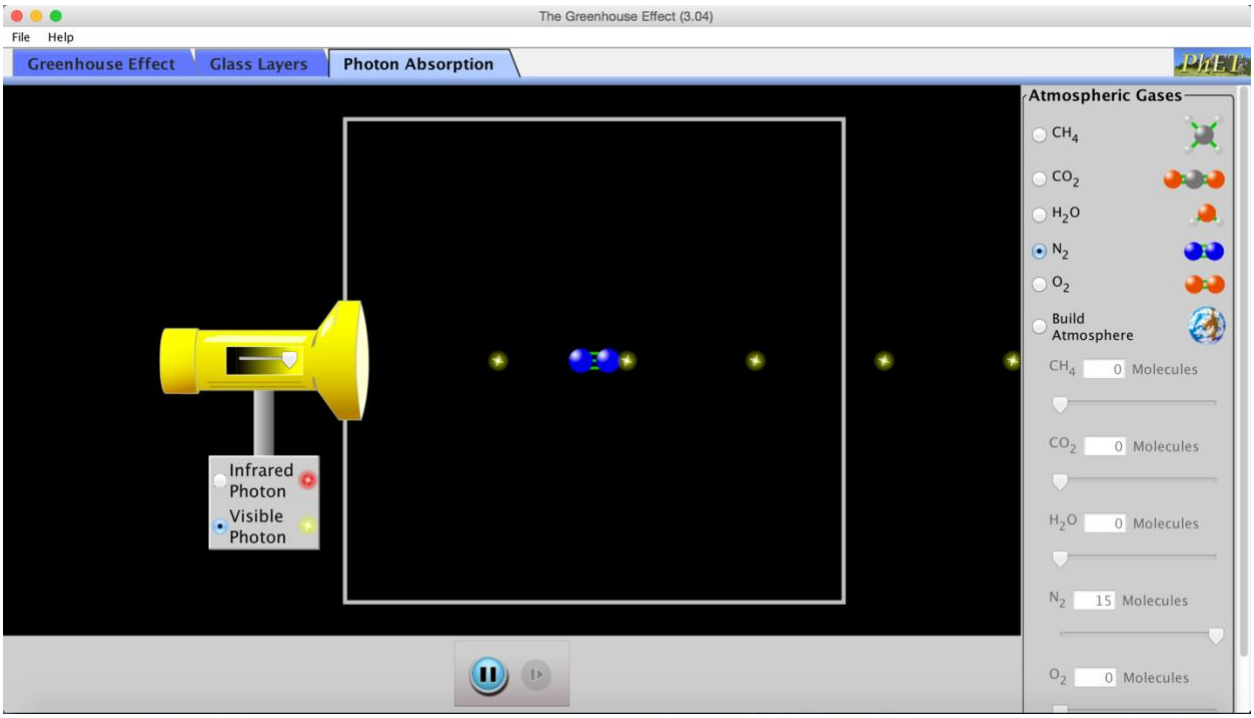


CO_2 and Infrared Photons: Under the "Atmospheric Gases" panel, select CO_2. On the "radiation gun" on the left-hand side of the screen, make sure that the "Infrared Photon" option is selected. Move the slider on the gun all the way to the right and observe how the infrared photons respond when they encounter the CO_2 molecule. Record your data on your worksheet.



N_2 and Visible Photons: Under the "Atmospheric Gases" panel, select N_2. On the "radiation gun" on the left-hand side of the screen, make sure that the "Visible Photon" option is selected. Move the slider on the gun all the way to the right and observe how the infrared photons respond when they encounter the N_2 molecule. Record your data on your worksheet.

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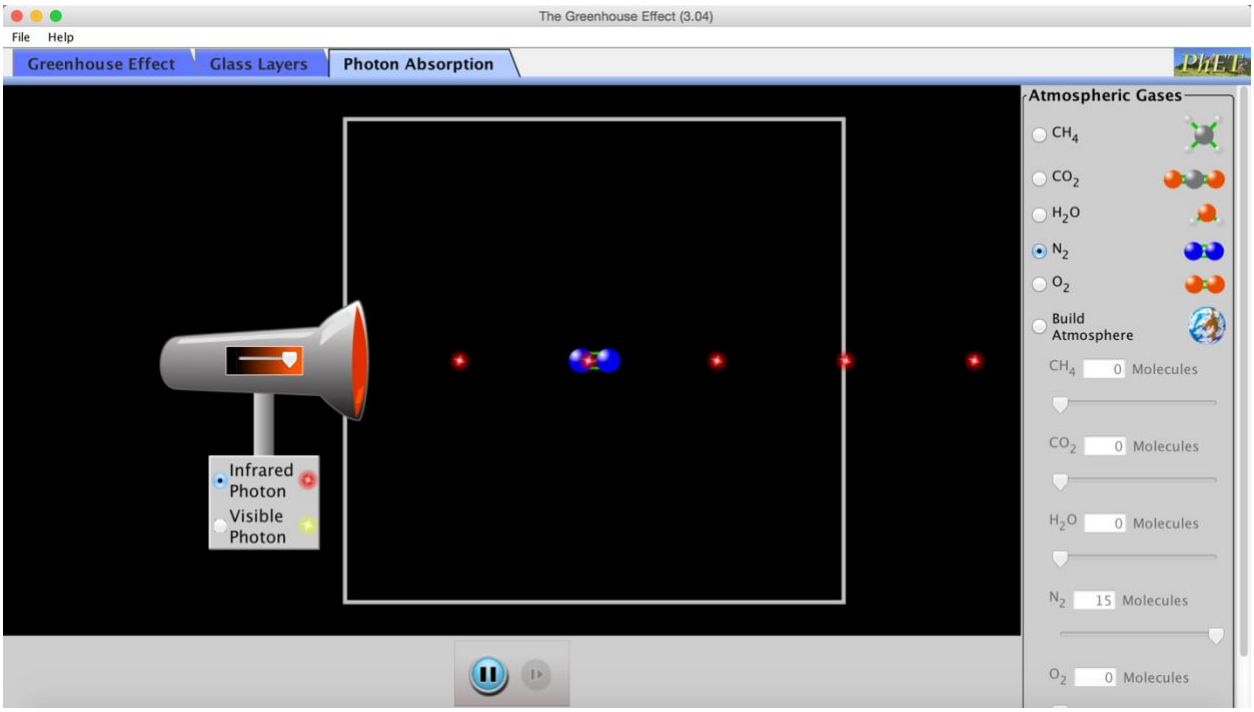

N_2 and Infrared Photons: Under the "Atmospheric Gases" panel, select N_2. On the "radiation gun" on the left-hand side of the screen, make sure that the "Visible Photon" option is selected. Move the slider on the gun all the way to the right and observe how the infrared photons respond when they encounter the N_2 molecule. Record your data on your worksheet.

Conclusions: Complete this section of your worksheet by answering the remaining questions. What differences did you notice between how different kinds of energy and different kinds of molecules interact in different ways?

B. Investigating how different gases in the atmosphere affect the Earth's temperature:

For the next questions, you will need to open the Greenhouse Effect Tab (in the upper left). The earth's atmosphere is comprised of a variety of gases. We will now look at a more complex model of how different kinds of radiation interact under different atmospheric conditions. For this section, you will be adjusting the concentration of greenhouse gases (gases like CO_2 which can absorb and re-emit infrared radiation) and you will observe the resulting differences in the patterns in the movement of light and infrared photons. You will also observe the impact that these changes have on the Earth's temperature.

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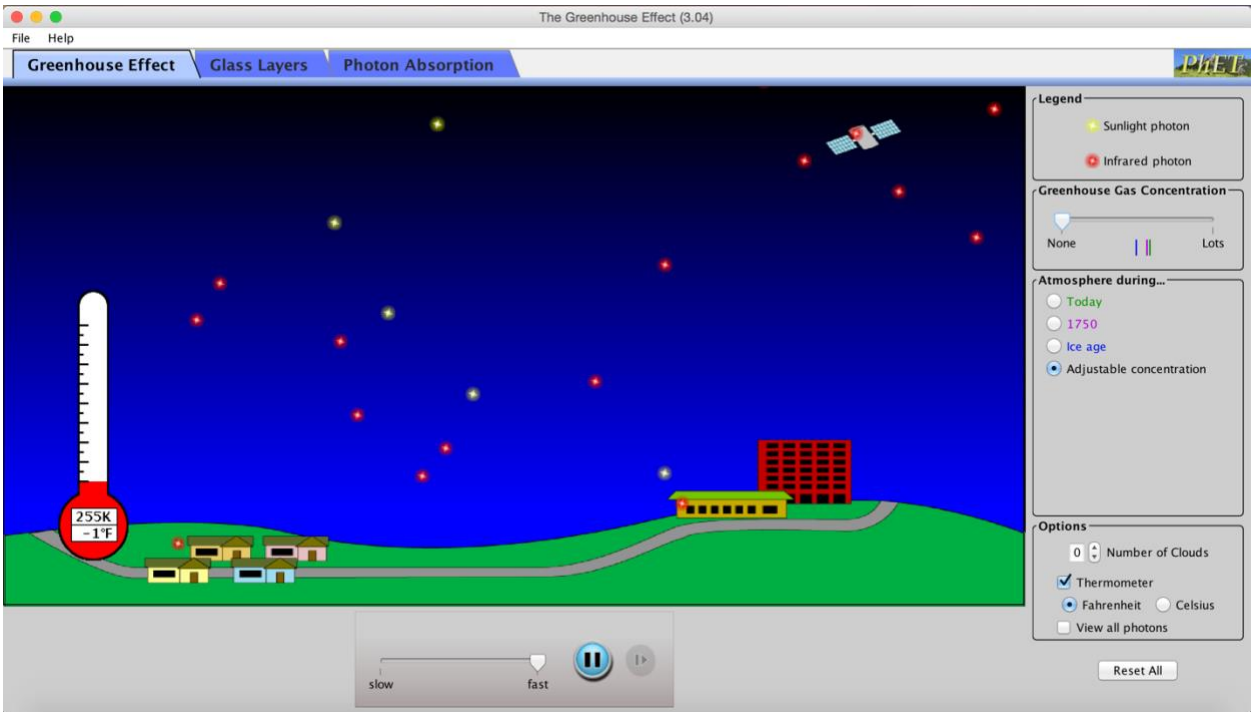
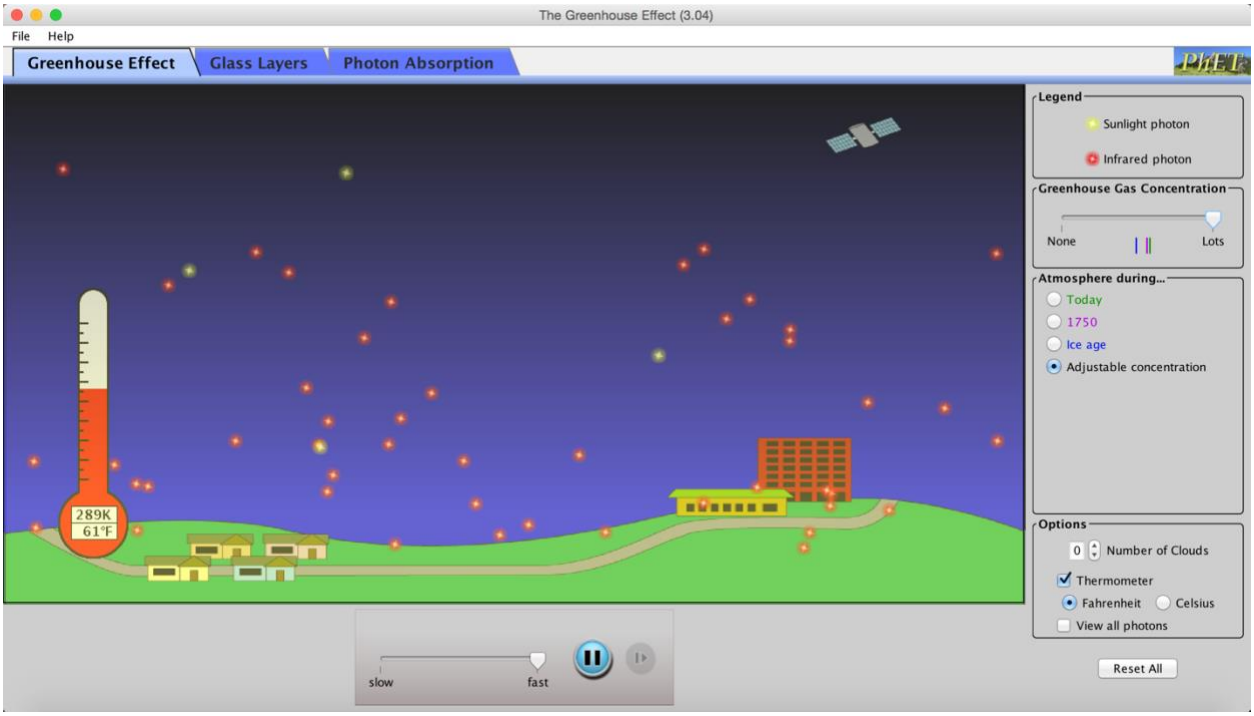


Low CO_2 Levels & Temperature: In the "Greenhouse Gas Concentration" panel, move the slider to "None". Watch the yellow sunlight photons as they move from outer space to the surface of the earth. Then watch the red infrared photons as they move from the surface of the earth to outer space. What observations can you make about their movement? Record your data on your worksheet.

Next look at the thermometer on the left-hand side of the screen. Record the temperature that occurs under these conditions. Record your data on your worksheet.



High CO_2 Levels & Temperature: In the "Greenhouse Gas Concentration" panel, move the slider to "None". Once again, observe the movement of both the yellow sunlight photons and the red infrared photons. What observations can you make about their movement? Record your data on your worksheet.

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Again, look at the thermometer on the left-hand side of the screen. Record the temperature that occurs under these conditions. Record your data on your worksheet.

Conclusions: Complete this section of your worksheet by answering the remaining questions. How did the changes to the concentration of greenhouse gases affect temperature? How does this relate to your observations from Part A?

C. Investigating why the Keeling Curve is important:

For the next questions, you will remain on the Greenhouse Effect Tab (in the upper left). Now you will be connecting the relationships between changing greenhouse gas concentrations and temperature to past, present, and future conditions.

Conclusions: Complete this section of your worksheet by answering the remaining questions. How does what you observed in Part C relate to the Keeling Curve? How does this relate to your observations from Part A? What can this tell us about future implications?

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Appendix: Tabletop Greenhouse Effect

Overview: students will use FACTS Bioreactors and seltzer tablets to measure the effects of increased greenhouse gas concentrations on temperature retention.

Materials: FACTS Bioreactors (1-2 per group), Alka-Seltzer tablets (one packet of two tablets per group), tap water, electrical source.

Student Instructions:

1. Use two FACTS Bioreactors. Be sure that your airlock has water in it.
2. Fill each bioreactor with 400 ml of tap water. Seal the containers. Move the thermometers so that they are above the waterline (use caution – glass thermometers can easily break!).
3. After ensuring that both containers are completely sealed and are air-tight, remove the stopper with the airlock from the access port of one of the bioreactors and add two Alka-Seltzer tablets. Immediately reinsert the stopper and seal tightly. Allow the tablet to react completely. Be sure to keep track which bioreactor was treated with the tablet.
    a. The tablet will add CO2 to the air of your bioreactor and increase CO2 levels above normal levels.
4. Turn on both of heaters by plugging them into an outlet. Ensure that the orange light inside the glass tubing of the heater turns on. If it does not, turn the heater onto a higher setting using the knob on top (arrows point which direction to turn).
    a. The temperature of the water has to be increased after the CO2 has been added in order to create an even dispersal of CO2.
5. Keep the heaters on until both reach 40-45^{o} C. If one reaches this temperature before the other, adjust the knob so that it stays within the correct temperature range while the other bioreactor is still heating.
6. Keep both bioreactors within a degree of each other for at least 2 minutes. When you have balanced the temperature of both bioreactors, unplug the heaters. Note the time.
7. Record the temperature of the air at 5 minute intervals for 30 minutes or until the temperature levels out (whichever comes first)
8. After you have completed recording the temperatures at each interval, begin graphing your results.
9. During or after your graphing, rinse out each bioreactor chamber in a sink with tap water and dry with a paper towel. Return your bioreactor to the location specified by your instructor.

Additional Notes:

- You may opt to add the Alka-Seltzer tablets and start heating the bioreactors prior to the start of class so that they are heated and ready for observation when the lab begins. Plan to allow at least 30 minutes for the bioreactor heaters to reach 40-45^{o} C from room temperature.
- It can be helpful to place a layer of insulation (such as a cloth towel or paper towel) between the bioreactor and the surface on which it is placed. Some surfaces can cause heat to dissipate away at varying rates, which can affect the experimental results. Also note drafts, heating/cooling, and ventilation in your room, as this can affect your results.
- To check your bioreactor to ensure that it is airtight, you can use the syringe and observe whether or not moving the plunger affects the water in the airlock (if the bioreactor is not airtight, it will lose CO2 and not show any differences from the control).
- **Practice this lab BEFORE trying it with students. It can be *very* difficult to minimize errors in this activity.**

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Appendix: Review and Asssessment

Introduction: In this section, we will discuss strategies to guide your students during review and assessment for a vocabulary-intensive unit.

While recent reforms to science education (as outlined by the NRC's *K12 Framework* and NGSS) minimize the emphasis on having students learn vocabulary, we have found that we cannot completely eliminate vocabulary from ecological instruction for a number of reasons. Most importantly, we have found that in order for students to sufficiently engage in reasoning and sense-making about ecological phenomena, they need to have an appropriate language with which to develop explanations and solutions.

However, in the FACTS curriculum, we view vocabulary as a *means to an end* and not as a central objective to the curriculum. In other words, we don't care very much whether students have memorized the definitions of terms, but whether they can accurately use those terms to describe and understand phenomena, and ultimately create evidence-based arguments, explanations, and solutions. We view vocabulary as part of a "sense-making toolkit" that enables students to organize their reasoning and argumentation.

As such, we recommend that you provide students with opportunities to practice mastering the vocabulary in this course while also recognizing that mastery of vocabulary is a secondary objective in these units. This means that assessing vocabulary can work as a formative assessment but is not ideal by itself as a summative assessment. The primary goal of this curriculum is to enable valid evidence-based reasoning and sense-making, and your summative assessments should reflect this.

There are a few strategies you might considering adopting to support these objectives:

- While multiple-choice assessments are provided in the weekly packets, we take the stance that these options should not be used by themselves as a final summative assessment.
    - You might consider assigning this as optional homework, allowing students to use a 3x5 card with handwritten notes, and/or assigning completion points in lieu of scores based on the percent correct.
- Teachers have also created hybrids of the multiple choice and short answer assessments, selecting some questions from each option. Their experiences suggest that the multiple-choice assessments help to prepare students for the more intellectually rigorous short answer questions.
- You might also consider having a space on a chalkboard/dry-erase board for publicly posting course vocabulary or hanging a large sheet of paper and adding vocabulary and definitions if students start to struggle.
- Teachers have also used vocabulary practice as an option for a bell-ringer activity, using options such as short, ungraded online quizzes to start class.

You as the instructor are best positioned to decide what will be most effective for your classroom. Feel free to use or disregard these suggestions as you see fit. However, we do strongly recommend that you avoid positioning memorization of vocabulary as one of the primary objectives of this course, and instead emphasize valid reasoning and sense-making about ecological phenomena as your top priority.

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Appendix: Addressing Climate Denial/Skepticism

Overview: In this section, we will discuss strategies to navigate ideologically driven opposition to climate science.

Introduction: It is well known that ideological preferences affect how individuals perceive evidence regarding climate science, particularly in the United States. This can make instruction on this topic especially challenging. In this unit, we opted to emphasize the molecular properties of greenhouse gases and de-emphasize discussions of policy decisions and sociological ramifications. This is for a number of reasons. First, the limited scope of a one-week unit would be easily overwhelmed by broader considerations. Second, there will be additional opportunities for discussions about policies and behavioral changes in later units on sustainability. Finally, we want students to understand where room for debate exists, and where it does not. The molecular properties of carbon dioxide are very well understood, and have been investigated since the mid-1800s (consider reading the following: https://daily.jstor.org/how-19th-century-scientists-predicted-global-warming/). As such, the question of whether or not increasing the levels of atmospheric carbon dioxide affects global surface temperature is essentially settled – we have known since the 1800s that rising levels of CO_2 will result in changes to the planet's average surface temperature.

This is a point that you may want to explicitly make to your students at some point during this unit (but ideally *not* at the beginning). In short, students are welcome to develop their own opinions about what responses to climate change are justifiable and warranted, but the evidence regarding the warming potential of greenhouse gases is not up for debate. Informed individuals can debate the merits of, say, a carbon tax or the Paris Accord (and certainly do debate this), but informed individuals cannot legitimately suggest that dramatic changes to atmospheric CO_2 levels would have no impact on global mean temperatures, ecosystem function, or human activity.

Our research has shown that some students may question the validity of climate data. In particular, students may question how we actually know the CO_2 levels and atmospheric conditions that existed hundreds of thousands of years ago. Some students have argued that there is no way to know if what we're experiencing today has occurred in the past or not. They often assume that conclusions about greenhouse gases and climate function result from faulty models built on erroneous assumptions. It may be helpful to anticipate these kinds of arguments and explicitly acknowledge why their arguments *might* seem plausible. It may also be helpful to explain how scientists know what they know, and how they acquired the data that enabled them to reach valid conclusions. One possible source for addressing these questions is https://climate.nasa.gov/news/2616/core-questions-an-introduction-to-ice-cores/

This may be a good unit to re-establish classroom guidelines for argumentation and remind students of the NGSS scientific and engineering practices. In particular, it may be especially helpful to inform students that they will need to be able to explain *how they know they are not wrong* … i.e. what evidence and reasoning supports their stance on this issue? How do they know that this evidence and reasoning is sufficient for supporting their current stance? For example, we know that **combustion produces CO_2, and CO_2 is a greenhouse gas; increasing levels combustion will increase levels of CO_2, resulting in warmer temperatures on average for the earth's surface**. None of these stances are disputable – we do not have any credible evidence at the moment that disproves any of these conditions, but we do have a plethora of evidence to confirm these statements. As such, we can use this as a heuristic with which to frame debates that occur during this unit.

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