Lesson 4: Fossil Fuels and Carbon Pools

Tab 1: Overview

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Students are introduced the Four Questions at a large scale to examine the major pools of carbon (with special attention to the fossil fuel pool). Then they look more closely at the Keeling Curve and examine how fossil fuels are formed and how we use them.

Guiding Question

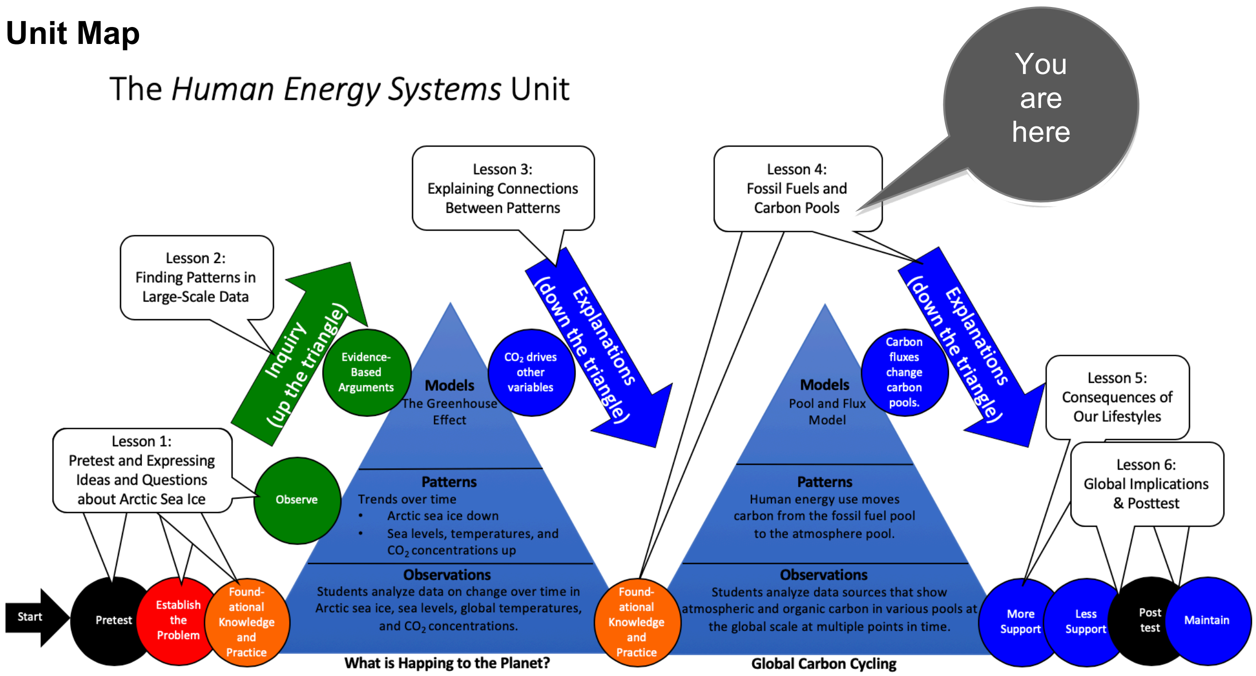
What causes and how can we predict changes in CO_2 concentrations?

Activities in this Lesson

- Activity 4.1: Questions for this Lesson (30 min)
- Activity 4.2: Carbon Pools and Fossil Fuels (35 min)
- Activity 4.3: Tiny World Modeling (50 min)
- Activity 4.4: Global Computer Model (50 min)
- Optional Activity 4.5: Effects of Seasons and Oceans (50 min)

Unit Map

The *Human Energy Systems* Unit



Tab 2: Learning Goals

Target Performances

Activity	*Target Performance*
Lesson 4 – Fossil Fuels and Carbon Pools (students as questioners, investigators, and explainers)	

Activity	*Target Performance*
Activity 4.1: Questions for this Lesson (30 min)	Students apply the large-scale Four Questions to two patterns in the Keeling curve (showing atmospheric CO_2 concentrations): the annual cycle and the long-term trend.
Activity 4.2: Carbon Pools and Fossil Fuels (35 min)	Students identify carbon pools in Earth systems and investigate the fluxes associated with human use of one pool: fossil fuels.
Activity 4.3: Tiny World Modeling (50 min)	Students investigate the relationship between pools and fluxes in a physical model of a tiny world, showing how changing photosynthesis, cellular respiration, and combustion fluxes can account for both an annual cycle and a long-term trend in the atmospheric CO_2 pool.
Activity 4.4: Global Computer Model (50 min)	Students use an online computer model to make quantitative predictions of how changes in photosynthesis, cellular respiration, and combustion fluxes will affect the long-term trend in the atmospheric CO_2 pool.
Optional Activity 4.5: Effects of Seasons and Oceans (50 min)	Students use a diagrammatic carbon cycle model to investigate how oceans and seasons in the Northern and Southern Hemispheres affect the annual cycle and a long-term trend in the atmospheric CO_2 pool

NGSS Performance Expectations

High School

- Ecosystems: Interactions, Energy, and Dynamics. HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.
- Earth's Systems. 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.
- Weather and Climate. HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
- Earth and Human Activity. HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
- Earth and Human Activity. HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

Middle School

- Waves and Electronic Radiation. MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

- MS-ESS2-1. Develop a model to describe the cycling of the Earth's materials and the flow of energy that drives this process.
- Human Impacts. MS-ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capital consumption of natural resources impact Earth's systems.
- Earth and Human Activity. MS-ESS3-5. Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.

Tab 3: Background Information

Three-dimensional Learning Progression (accordion)

Understanding how the Keeling Curve represents patterns in the Earth's atmosphere. The Keeling Curve is often presented as easily interpretable evidence that the concentration of CO_2 in the Earth's atmosphere is increasing, but our research shows that interpreting this graph presents many challenges for students. In particular:

- The variable measured—concentration of CO_2 in parts per million—is not easy for students to understand.
- It is not at all clear to students how measurements of CO_2 concentration on a mountain in Hawaii might be related to CO_2 concentrations in other parts of the world. The Pumphandle Video, introduced to students in Lesson 2, shows the complex relationships among measures of CO_2 concentration taken at different locations on Earth. (See below for a description of the Pumphandle Video.)

Explaining patterns of change in CO_2 concentrations. We assume that students studying this Unit will be familiar with carbon-transforming processes (photosynthesis, cellular respiration, combustion, digestion, biosynthesis) in individual plants and possibly animals and decomposers. In this Lesson they consider how these processes affect carbon pools on a global scale.

There are two patterns evident in the Keeling Curve: an annual cycle caused primarily by changing rates of photosynthesis in the Northern Hemisphere and a long-term increase caused primarily by burning of fossil fuels and land-use changes that release carbon from biomass or soil carbon into the atmosphere. This lesson focuses on helping students use *pool-and-flux* models to explain those patterns. There are many fluxes that move carbon into or out of the atmosphere, but most of those are balanced by other fluxes. The flux from fossil fuel combustion, in particular, is not balanced: it moves carbon permanently from the fossil fuel pool into the atmosphere.

However, most students rely on simpler heuristics or rules of thumb rather than pool-and-flux models to explain patterns of change, including *the good vs.bad heuristic* and the *correlation heuristic.*

- *Good vs. bad heuristic* They use an informal frame that describes things that happen to the environment as good (e.g., less pollution) or bad (e.g., using fossil fuels). For instance, here is a reason that one student gave for cutting fossil fuel use: "*If it cuts down and maintain a low level use, the air will clear up and it will be good for animals and humans to breath clean air."* Students using this heuristic also connect bad actions to bad outcomes: "*[b]ecause I think we've reached a point where we've done too much damage to earth, personally. And I don't think we can come back from that."*
- *Correlation heuristic*: These students often applied the correlation heuristic, conflating changes in flux (slope of the graphed line) with changes in pool size (value on the Y-axis). The following written response reflects this type of thinking: "*fossil fuels help to produce CO_2*

so if we cut it in half it would decrease." Note how this student used "it" twice in the same sentence, perhaps without recognizing that each "it" had a different meaning:

- *…if we cut it* (CO_2 emissions—the flux arrow) *in half,*
- *…it* (CO_2 concentration—a measure of the size of the atmospheric CO_2 pool) *would decrease.*

Predicting patterns of change in CO_2 concentrations. The good vs. bad heuristic and the correlation heuristic can be useful for many purposes, helping us to identify environmentally responsible actions and processes that cause climate change. However, these approaches often lead to spurious quantitative reasoning, such as when students conflate a change in flux with a change in pool size: Cutting CO_2 emissions in half does NOT decrease CO_2 concentration in the atmosphere; it merely makes the concentration go more slowly.

So in order to make accurate predictions, students must use quantitative reasoning to balance all the CO_2 fluxes into and out of the atmosphere. Activities 4.3, 4.4, and 4.5 engage them in using the balance of fluxes to make predictions about changes in pool sizes in increasingly sophisticated ways.

Key Ideas and Practices for Each Activity (accordion)

Activity 4.1 Introduces students to the two patterns in the Keeling Curve (the short-term seasonal fluctuation and the long-term trend) and asks them to document their initial ideas about these two key patterns. Because increasing atmospheric CO_2 is the driver of all other Earth Systems explored in this unit, we spend more time on this pattern than others. In previous lessons they collected evidence that shows that this phenomenon *is* happening; in this activity they go one step further and explain *why* they think this is happening. Because this is an initial ideas stage, students should not be penalized for incorrect ideas.

Activity 4.2 takes a step back from the regular progression of the unit to examine fossil fuels. In the organismal units, this would be the equivalent of the "foundational knowledge" activity. Students examine fossil fuels in three different ways. The first is through introduction to the Carbon Pools Question, where they examine the different Carbon Pools in the unit. They then zoom into the fossil fuels pool specifically to learn about (a) the molecular structure of fossil fuels, and (b) how fossil fuels were formed. This provides the foundational information for understanding why fossil fuels burn (they are constructed from organic molecules).

Activity 4.3 uses a hands-on activity (the Tiny World Modeling game) to help students figure out explanations for both the annual cycle and the long-term trend in the Keeling Curve. The Tiny World has three carbon pools: (a) atmospheric CO2, (b) organic carbon in living systems and soils, and (c) fossil fuels. Carbon atoms move among these pools in three carbon fluxes associated with carbon-transforming processes that students have studied before:

- Photosynthesis moves carbon atoms from the atmosphere to organic matter in plants, animals, and soil.
- Cellular respiration moves carbon atoms from organic matter in plants, animals, and soil to the atmosphere
- Combustion moves carbon atoms from the fossil fuels pool to the atmosphere.

In playing the game students see how the balance among fluxes determines changes in pools, and how seasonal variations in fluxes and combustion of fossil fuels leads to patterns like those in the Keeling Curve.

In **Activity 4.4** students use a computer model to make quantitative predictions about effects of changes in pools and fluxes. The computer model has the same pools and fluxes as the Tiny World model (Activity 4.3), but the sizes of pools and fluxes are based on current data.

Students can control the size and timing of changes in fluxes and see projections of the long-term effects (50 years) for those changes.

Activity 4.5 is an optional (two turtle) activity that dives into the seasonal fluctuation of carbon dioxide in the atmosphere pool and into other pools and fluxes in the global system. Students identify photosynthesis as the specific flux driving seasonal variations in CO_2 concentrations. They view videos with animations of data to show how variations in sunlight in the hemispheres drive different yearly patterns of concentration. They also use a global carbon cycling diagram to discuss other pools and fluxes (associated with oceans and land use change) and make predictions about the effects of decreasing use of fossil fuels. These explanations and predictions are the most complex in the unit.

More information on the Pumphandle Video.[1] This video provides a visual representation of the data that has been collected of carbon dioxide concentrations in the atmosphere and how it has changed over time. Tell students that when they are watching the video, to see if the same seasonal and upward trends that are present in the Keeling Curve are present in other places on the planet where data about carbon dioxide are collected. Watch the video, which is 3 minutes and 35 seconds long.

- 0:00-0:30—Point out to students the various pieces of information in this image. Each colorful dot represents a location on the planet where data about atmospheric carbon dioxide has been collected over time. The data are aligned by latitude, with the right side of the graph showing the most northern points. The bright red dot represents Mauna Loa. The bright blue dot represents the South Pole in Antarctica. They can see where these locations are on the small map on the right side of the image.
- 0:30-1:00—Point out that the graph on the right side of the images is charting data from both Mauna Loa (northern hemisphere) and also Antarctica (southern hemisphere). Ask them if they notice the difference between the data from the northern and southern hemispheres. What might be the reason for the larger flux in the northern hemisphere, and the smaller flux in the southern hemisphere? (There is more land and more plants in the middle of the Northern Hemisphere compared to the South Pole.) Point out the small circle on the right side of the image that shows the time of year.
- 1:00 – Around this time in the video, students will notice that some of the CO_2 levels recorded at different places on the planet fluctuate much more dramatically than at Mauna Loa. Ask them why they think this might be happening. Point out that the Mauna Loa data does not fluctuate as much because the readings are taken on top of a mountain that is surrounded by ocean, so the signals from the plants and human emissions (both releasing and taking in CO_2) do not impact the reading as dramatically.
- 1:15 – Pause the video and ask students to notice during which months of the year the CO_2 levels are highest in the northern hemisphere. Ask them to make connections to what they see on the screen and their image of the Keeling Curve. Point out that this is the seasonal cycle. Then, ask students to notice that the line on the left is continuously rising. Ask them

[1] This video is a nice opportunity to point out that even though there are short-term variations in the temperature and CO_2 levels, that the overall trend is still increasing. Students may ask "If global warming is happening why was it so cold this winter?" Even as the global temperatures continue to increase, we will still see unusually cold winters and even summers. These short-term cold periods (e.g., one season or month) are due to local weather, short-term changes in the movement of polar winds, and ocean circulations, and do not reflect the overall warming trend. However, it is predicted that climate change might make some of these local, extreme weather events more severe over a long-time scale.

which line on the Keeling Curve image on their worksheet corresponds with this increase. Point out that this is the upward trend.

- 2:00 – Remind students that in addition to having data about CO_2 in the atmosphere from the past 60 years from Keeling's and others' experiments, we also have information about how much carbon was in the atmosphere from many years in the past. We get these data from studying carbon isotopes in the ice cores in Antarctica.
- 3:10 – With the long-term carbon dioxide levels on display in the graph, ask the students what they think this graph is showing. Point out that although the levels of carbon dioxide on the planet have fluctuated over time, in millions of years they have never reached the levels that they are today: nearly 400 ppm

Content Boundaries and Extensions (accordion)

The primary focus of this lesson is on understanding how pools and fluxes, particularly the unbalanced flux from combustion of fossil fuels, Activities 4.1 through 4.4 focus on terrestrial carbon pools and hands-on or computer models. Activity 4.5, focusing on a graphic model and including fluxes into and out of the oceans, is an optional extension.

Key Carbon-Transforming Processes: Combustion, Photosynthesis, Cellular Respiration

Activity 4.1: Questions for this Lesson (30 min)

Tab 1: Overview and Preparation

Target Student Performance

Students apply the large-scale Four Questions to two patterns in the Keeling curve (showing atmospheric CO_2 concentrations): the annual cycle and the long-term trend.

Resources You Provide

- 3.3 Explaining Relationships Between Earth Systems Worksheet (completed from Lesson 3)

Resources Provided

- 4.1 Questions for this Lesson PPT
- (Extending the learning) *New York Times* Keeling article: https://nyti.ms/2jCmhVE
- (Optional) Pumphandle Video (discussed in Background Information for this lesson

Recurring Resources

- Learning Tracking Tool for Human Energy Systems (1 per student)
- Assessing the Learning Tracking Tool for Human Energy Systems
- Four Questions 11 x 17 Poster or Handout
- (Optional) Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half (1 per student)
- (Optional) Assessing the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half

Setup

Print one copy of Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? per student if you are using it and one copy of the Learning Tracking Tool for Human Energy Systems per student. Prepare computer with an Internet connection to view the videos online.

Tab 2: Directions (accordion for individual steps in directions)

1. Use the instructional model to show students where they are in the course of the unit. Show Slide 2 of the 4.1 Questions for this Lesson PPT.
2. Review what students have learned. Show Slides 3-7. Remind students that in the previous activities and lessons they used evidence to construct explanations about how increasing levels of CO_2 in the atmosphere drive other changes in global systems. In this Lesson, they will examine more closely *why* and *how* CO_2 levels are increasing. Before we do that, though, we will share our initial ideas about one specific Earth system: The Keeling Curve.
3. Help students identify the two patterns in the Keeling Curve. Ask students to look at the graphs on Slide 9 and to identify the patterns that they see. Use Slide 10 to provide names for the patterns: The Annual Cycle and the Long-term Trend. Optional: Show students the Pumphandle Video and discuss how the patterns in data from Hawaii are also patterns observed in many other locations on Earth.
4. Elicit students' initial ideas about the Annual Cycle and the Long-term Trend

Ask students to share their initial ideas about the first two questions on Slide 11. If you are using a Driving Question Board, you may want to record those ideas for later discussion.

5. Introduce or review the Large-scale Four Questions.

Show Slide 12, pass out the Four Questions Handout with checklist, and show students the Four Questions 11x 17 Poster. If your students studied the *Ecosystems* unit, they will be familiar with the Four Questions from that unit. If they have studied other macro-scale *Carbon TIME* units, remind them of the Three Questions. They will use the Four Questions to define what makes a good explanation. An overview of the first column of the table—the questions themselves—will be sufficient for now. They will discuss the Four Questions later in more detail.

6. (Optional) Have students complete the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half?

If you decide to use the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? Show Slide 13 and have students complete it and share their ideas. See Assessing the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? and Using Big Idea Probes for suggestions about how to use the Big Idea Probe.

7. Have a discussion to introduce the Learning Tracking Tool for this activity.

Show Slide 14 of the 4.1 Questions for this Lesson PPT.

- Pass out a Learning Tracking Tool for Human Energy Systems to each student.
- Explain that students will add to the tool after activities to keep track of what they have figured out that will help them to answer the unit driving question.
- Discuss goals for this lesson.
- Have students write the activity name in the first column, "Questions for this Lesson."
- Have a class discussion about what students figured out during the activity that will help them in answering the lesson driving questions:
  - What causes the annual cycle: CO_2 concentrations in Hawaii to go down every summer and up every winter?
  - What causes the long-term trend: CO_2 concentrations to go up every year?
  - How can we predict what will happen to CO_2 concentrations in the future?
- When you come to consensus as a class, have students record the answer in the second column of the tool.
- Have a class discussion about what students are wondering now that will help them move towards answering the unit driving question. Have students record the questions in the third column of the tool.
- Have students keep their Learning Tracking Tool for future activities.
- Example Learning Tracking Tool

Activity	What We Figured Out	What We are Asking Now
Activity 4.1: Questions for this Lesson	*Increases in atmospheric CO_2 are driving changes in other Earth systems.* *The Keeling Curve shows both an annual cycle and a long-term upward trend in CO_2 concentrations in Hawaii.*	*What is causing the annual cycle?* *What is causing the long-term trend?*

Tab 3: Assessment

This introductory activity has several opportunities for formative assessment:

- Use the ideas students share about patterns in the Keeling curve (Slide 9) as a "baseline" for where their understanding is at this point. Even with the jigsaw activity in Lesson 2, students may still be "warming up" to the data presented in this graph. Use this activity to determine where their ideas are at this point in the unit. They may still be uncertain about what the two different lines in the graph mean and represent, and what causes the patterns.
- Students' ideas about the questions on Slide 11 will give you an initial view of how students are thinking about the causes for the patterns in the Keeling curve. This will be the main focus for Activities 4.3 and 4.5.
- Students' answers to the Big Ideas Probe will provide an initial view of students' approaches to predicting how changes in fossil fuel emissions will affect CO2 concentrations in the future. This will be the main focus for Activities 4.4 and 4.5.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

- Break students up into groups and have each group summarize the main takeaways from each slide 3-7. Have the groups share these summaries with the rest of the class.

Modifications (Accordion)

Extending the Learning (Accordion)

The *New York Times* has an interesting article on Charles David Keeling and his research: https://nyti.ms/2jCmhVE. The Keeling Curve is often mentioned in the news and other media. Have students bring in articles that mention how many parts per million of carbon dioxide are currently in the atmosphere.

Activity 4.2: Carbon Pools and Fossil Fuels (45 min)

Tab 1: *Overview and Preparation*

Target Student Performance

Students identify carbon pools in Earth systems and investigate the fluxes associated with human use of one pool: fossil fuels.

Resources Provided

- 4.2 Carbon Pools and Fossil Fuels PPT
- 4.2 Carbon Pools and Fossil Fuels Reading (1 per student)
- Time-lapse history of CO_2 Emissions: https://www.youtube.com/watch?v=SAhZ1fA1AJs

Recurring Resources

- Learning Tracking Tool for Human Energy Systems (1 per student)
- Assessing the Learning Tracking Tool for Human Energy Systems
- Four Questions 11 x 17 Poster and/or Handout (1 per student)
- Questions, Connections, Questions Student Reading Strategy

Setup

Print enough copies of the 4.2 Carbon Pools and Fossil Fuels Reading and Four Questions Handout so that each student has one copy of each. Prepare a computer and projector for the 4.2 Carbon Pools and Fossil Fuels PPT. You may want to print and post the Four Questions Large Poster for the rest of the unit.

Tab 2: Directions (accordion for individual steps in directions)

1. Use the instructional model to show students where they are in the course of the unit.

Show Slide 2 of the 4.2 Carbon Pools and Fossil Fuels PPT.

2. Use the Four Questions to engage students in a discussion about scale.

Display Slide 3. Tell students that this unit is different from other *Carbon TIME* units because of the *scale*. Instead of looking at how carbon and energy move through an animal or a plant or a decomposer or an ecosystem, we are looking at how carbon and energy move around the entire world (i.e., at a large scale). By *world*, we mean the Earth and atmosphere for matter, and the sun and space for energy.

3. Discuss large-scale carbon pools.

Use Slide 4 of 4.2 Carbon Pools and Fossil Fuels PPT to introduce the main image for this unit.

- Tell students that we will use this picture to talk about how carbon and energy move through our world. This picture represents just a small portion of the larger Earth systems we are examining in this unit.
- Ask students for initial observations about what this picture has in it and where they see different Earth systems represented.
- Display Slide 5. Use the animation to make connections between the image and the more abstract "box diagrams" we use to represent the carbon pools.
- You may want to point out two interesting things about these pools:

- The biomass pool contains carbon found in the form of living things (including people) and recently living plants and animals. Most biomass on the earth is stored in the wood of trees and other plants.
- The soil organic carbon pool is a large pool of carbon (as large as the atmosphere and biomass pools combined). It contains carbon in the form of dead organisms (plants, animals, and decomposers) and living decomposers.

4. Introduce students to three global carbon pools.

Use Slide 6 to introduce students to the language you will use to discuss pools of carbon at a global scale: **Plants, animals, and soil organic carbon pool), atmosphere (inorganic carbon pool),** and **fossil fuels (organic carbon pool)**.

- Note that the ocean pool is intentionally omitted here, even though the ocean stores a lot of carbon.

5. Introduce the fossil fuels pool.

Display Slide 7 and tell students that they will spend the rest of the activity talking about one particular carbon pool: the fossil fuels pool. Ask students: *"What are fossil fuels?"* and *"Where do they come from?"* and *"How do we use them?"*

After you hear their initial ideas, use Slide 8 to ask students to share any ideas about the three fossil fuels they see in the slide: coal, oil, and natural gas.

6. Zoom into fossil fuels.

Use Slides 9-13 to "zoom" into fossil fuels at a molecular scale.

Using the slides, lead the students through a discussion in which they compare the molecules of gasoline/octane to other molecules to decide if gasoline/octane is organic or inorganic. Remind students that in *Carbon TIME* units, organic molecules 1) are carbon based, and 2) contain C-C and C-H bonds.

Display Slide 14. Tell students that fossil fuels contain chemical energy that is very useful to humans.

7. Have students read the Carbon Pools & Fossil Fuels Reading

Show Slide 15. Give each student a copy of 4.2 Carbon Pools & Fossil Fuels Reading and a copy of the Four Questions Handout (or have them take out their existing copies). Have students read 4.2 Carbon Pools & Fossil Fuels Reading using the Questions, Connections, Questions Reading Strategy. See the Questions, Connections, Questions Reading Strategy Educator Resource document for information about how to engage students with this strategy. Put a copy of the Four Questions 11 x 17 Poster on the wall for reference if it is not there already.

8. Overview and discussion of how fossils fuels are formed.

Use Slides 16-18 to briefly overview how fossil fuels form. Key information to point to during this presentation is that fossil fuels were formed from dead plants and animals that were exposed to heat and pressure over time. This is why fossil fuels contain energy-rich C-C and C-H bonds, and this is also the reason that we label fossil fuels pool an "organic" pool.

Display Slide 19 to aid in discussion about "Where does chemical energy in fossil fuels come from?" Remind them of the Four Questions.

9. Use the Carbon Cycling and Energy Flow Question for fossil fuels.

Display Slide 20. Tell students they are going to focus on the carbon cycling question and the energy flow question as it pertains fossil fuels.

Use Slides 21-23 to discuss how fossil fuels are formed, extracted and combusted.

Use Slides 24-25 to show how the carbon cycles and the energy flows in this same system.

Display Slide 26. Use the figure to discuss the role of fossil fuels in the overall carbon cycle.

Use Slide 27 to further discuss carbon cycling and energy flows.

10. Introduce the Stability and Change Question

Display Slide 28. Tell students they are going to focus on the stability and change question.

Display Slide 29 to start a discussion about how humans started using fossil fuels.

Slide 30 continues the conversation about how human still use fossil fuels today.

Show Slide 31. Tell students they will now watch a time-lapse video showcasing how CO_2 emissions have changed overtime. Have students share patterns they noticed as well as overall impressions.

Display Slide 32 to discuss the stability and change question.

11. Have a discussion to complete the Learning Tracking Tool for this activity.

Show Slide 33 of the 4.2 Carbon Pools & Fossil Fuels PPT.

- Have students take out their Learning Tracking Tool for Human Energy Systems.
- Have students write the activity name in the first column, "Carbon Pools and Fossil Fuels."
- Have a class discussion about what students figured out during the activity that will help them in answering the lesson driving questions:
  - What causes the annual cycle: CO_2 concentrations in Hawaii to go down every summer and up every winter?
  - What causes the long-term trend: CO_2 concentrations to go up every year?
  - How can we predict what will happen to CO_2 concentrations in the future?
- When you come to consensus as a class, have students record the answer in the second column of the tool.
- Have a class discussion about what students are wondering now that will help them move towards answering the unit driving question. Have students record the questions in the third column of the tool.
- Have students keep their Learning Tracking Tool for future activities.
- Example Learning Tracking Tool

Activity	What We Figured Out	What We are Asking Now
Activity 4.2: Carbon Pools and Fossil Fuels	*Fossil fuels are organic materials from plants and animals that were buried millions of years ago.* *Burning fossil fuels releases energy and CO_2.* *Humans are burning more and more fossil fuels.*	*How does burning fossil fuels affect CO_2 concentrations?*

12. Have students complete an exit ticket.

- Show Slide 35 of the 4.2 Carbon Pools & Fossil Fuels PPT.
- Conclusions: What are fossil fuels and how did they form?

- Predictions: How does burning fossil fuels affect CO_2 concentrations?
- On a sheet of paper or a sticky note, have students individually answer the exit ticket questions. Depending on time, you may have students answer both questions, assign students to answer a particular question, or let students choose one question to answer. Collect and review the answers.
- The conclusions question will provide you with information about what your students are taking away from the activity. Student answers to the conclusions question can be used on the Driving Question Board (if you are using one). The predictions question allows students to begin thinking about the next activity and allows you to assess their current ideas as you prepare for the next activity. Student answers to the predictions question can be used as a lead into the next activity.

Tab 3: Assessment

Students will not have complete accounts of where the energy in fossil fuels comes from and where it goes after fossil fuels are burned. Check during this activity to see where their ideas are as you begin to discuss fossil fuels.

Tips

- You may want to revisit the Powers of Ten 11 x 17 Poster (from the *Systems and Scale* unit) to refresh students' memories about what we mean by "scale" when we zoom into fossil fuels.
- Students may have questions at this point about the difference in the way we define "organic" in the *Carbon TIME* units, and other meanings of this word. Remind them that in the *Carbon TIME* units, "organic" things contain C-C and C-H bonds. "Inorganic" things do not contain C-C and C-H bonds. Fossil fuels contain C-C and C-H bonds that make them a rich source of energy for people—this means that fossil fuels are organic, even though they are not living. If students raise these questions, point out that our definition of organic is also not the same as the definition they might see in a grocery store to refer to food produced without using pesticides, fertilizers, antibiotics, or growth hormones.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

Have students read in pairs and discuss Questions, Connections, Questions with their partners.

Modifications (Accordion)

Extending the Learning (Accordion)

- Have students record different ways they use fossil fuels in one day of their lives and bring their journals to class. Check to see if they make the connection that using electricity uses fossil fuels (assuming the electricity comes from a coal-fired power plant). At this point in the unit, they may not be able to make this connection, but it could serve as a way to introduce the idea for later discussion.
- Have students research things that are made using fossil fuels and make a list of products. They might be surprised how many things they use every day are made from oil and petroleum!

The overview of fossil fuel formation is very short in this Lesson. As an extension activity, have students research in more detail how different fossil fuels are formed, how they are extracted from the Earth, and how we use them.

Activity 4.3: Tiny World Modeling (50 min)

Tab 1: Overview and Preparation

Target Student Performance

Students investigate the relationship between pools and fluxes in a physical model of a tiny world, showing how changing photosynthesis, cellular respiration, and combustion fluxes can account for both an annual cycle and a long-term trend in the atmospheric CO_2 pool.

Resources You Provide

- Markers for Tiny World Pool and Flux Activity to be used on the placement (30 per pair of students)

Resources Provided

- 4.3 Tiny World Modeling PPT
- 4.3 Tiny World Pool and Flux Placement (1 per pair of students)
- 4.3 Tiny World Modeling Worksheet (1 per student)
- 4.3 Grading the Tiny World Modeling Worksheet

Recurring Resources

- Learning Tracking Tool for Human Energy Systems (1 per student)
- Assessing the Learning Tracking Tool for Human Energy Systems

Setup

Print the 4.3 Tiny World Pool and Flux Placemats. You may want to laminate them first in order to make them last longer. Print one copy of 4.3 Tiny World Modeling Worksheet for each student. Prepare a computer and projector to display the 4.3 Tiny World Modeling PPT.

Tab 2: Directions (accordion for individual steps in directions)

1. Use the instructional model to show students where they are in the course of the unit.

Show Slide 2 of the 4.3 Tiny World Modeling PPT.

2. Introduce a Pool and Flux Model to Explain the Keeling Curve

Ask students to verbally share accounts of the Keeling Curve to activate their prior knowledge.

- Display Slide 3 of 4.3 Tiny World Modeling PPT, which shows an image of the Keeling Curve.
- Ask the students about patterns they notice on the graph.

3. Share Goals for Lesson 4.3

Display Slide 4 of 4.3 Tiny World Modeling PPT. Share with students their three goals that they want to figure during this activity:

- what makes CO_2 concentrations in Hawaii go up every winter and down every summer,
- what makes CO_2 concentrations a little higher each year, and
- how to predict future CO_2 concentrations

4. Review pools and fluxes in the global carbon cycle.

Display Slide 5 of 4.3 Tiny World Modeling PPT. Use the animation to review and make connections between the image and the more abstract “box diagrams” we use to represent the carbon pools.

You may want to point out two interesting things about these pools:

- The biomass pool contains carbon found in the form of living things (including people) and recently living plants and animals. Most biomass on the earth is stored in the wood of trees and other plants.
- The soil organic carbon pool is a large pool of carbon (as large as the atmosphere and biomass pools combined). It contains carbon in the form of dead organisms (plants, animals, and decomposers) and living decomposers.

5. Review the three global carbon pools.

Display Slide 6. Review the atmospheric, organic carbon and fossil fuels pools. Recognize where carbon is in each pool.

Turn to Slide 7 of 4.3 Tiny World Modeling PPT. Use the figure to ask some more in-depth questions about its content, such as:

- Where is the organic matter pyramid on the figure?
- Why doesn’t energy cycle like matter? (answer: energy flows, matter can be recycled)
- Why is the photosynthesis arrow so wide? (answer: this is the only process that incorporates “new” carbon atoms into an ecosystem, converting inorganic carbon molecules to organic carbon molecules)
- What ultimately happens to **most** of the carbon that enters the ecosystem through photosynthesis? (answer: it is returned to the atmosphere through cellular respiration carried out by producers, herbivore, carnivores, and decomposers)

6. Review fluxes as they relate to the global carbon cycle

Use Slide 8 to define fluxes as rates (mass/time). Explain the terms, movements and fluxes. Turn to Slide 9 to further discuss fluxes and to ask some more in-depth questions about its content.

7. Introduce the Tiny World Modeling Activity

Display Slide 10. Hand out one 4.3 Tiny World Modeling Worksheet to each student along with a 4.3 Tiny World Pool and Flux Placement and 30 markers. The game can be done by individual students or in pairs. Each student keeps his/her own data and graphs.

Use Slides 10-11 to explain the game and setup.

Show Slide 12. As a class, run through scenario 1 of Tiny World Modeling: a world with no seasons and balanced fluxes. In this scenario, we will have 15 carbon atoms in the organic pool and 5 in the atmospheric pool. Have students put the appropriate number of markers on placemat and starting points on the graph. Both the photosynthesis and cellular respiration rate are at 2 carbon atoms/year. Have class work through years by moving chips according to the fluxes and recording each year’s result in the chart and on the graph. Students should connect the dots for the organic (green) pool with a dashed line and use a solid line for the inorganic atmospheric pool.

Have students play through year 5, recording and graphing their data as they go.

Have students compare their results to Slide 12.

8. Students continue the Tiny World Modeling Activity

Tell students they can try scenarios 2, 3 and 4. Display Slides 13-15 of 4.3 Tiny World Modeling PPT when students are ready to check their completed graphs.

9. Introduce Idea of Net Flux

When finished with the Tiny World Modeling Activity, Use Slide 16 to have students summarize what they found about the relationship between pool size and fluxes as a whole class. Don't show the bullets until they are done summarizing.

10. Discuss general patterns and rules and connect to Keeling Curve

Display Slide 17. Have students compare the Keeling Curve graph from earlier to their results from scenario 4: Tiny World Model with seasons and combustion. Discuss patterns and rules from the modeling activity that can be seen in the Keeling Curve graph.

11. Students Complete Tiny World Model Worksheet

Students complete pages 6 and 7 (explaining the annual cycle and the long-term trend on the Keeling Curve) of 4.3 Tiny World Modeling Worksheet, using the Four Questions handout and checklist.

12. Discuss Good Explanations

Using Slides 18-21, have students trade their explanations with a partner and check each other's explanations using a different color pen. You may choose to allow students to revise their own explanations in a different color after receiving feedback.

13. Have a discussion to complete the Learning Tracking Tool for this activity.

Show Slide 22 of the 4.3 Tiny World Modeling PPT.

- Have students take out their Learning Tracking Tool from the previous lesson.
- Have students write the activity name in the first column, "4.3 Tiny World Modeling."
- Have a class discussion about what students figured out during the activity that will help them in answering the lesson driving questions:
  - What causes the annual cycle: CO_2 concentrations in Hawaii to go down every summer and up every winter?
  - What causes the long-term trend: CO_2 concentrations to go up every year?
  - How can we predict what will happen to CO_2 concentrations in the future?
- When you come to consensus as a class, have students record the answer in the second column of the tool.
- Have a class discussion about what students are wondering now that will help them move towards answering the unit driving question. Have students record the questions in the third column of the tool.
- Have students keep their Learning Tracking Tool for future activities.
- Example Learning Tracking Tool

• Activity	• What We Figured Out	• What We are Asking Now
Activity 4.3: Tiny World Modeling	*The size of the atmospheric carbon pool can change depending on the balance of fluxes (photosynthesis, cellular respiration, combustion) into and out of the pool.*	*How are unbalanced fluxes affecting the Earth's atmospheric CO_2 pool?*

14. Have students complete an exit ticket.

- Show Slide 24 of the 4.3 Tiny World Modeling PPT.

- Conclusions: What fluxes change the size of the atmospheric CO_2 pool?
- Predictions: How are those fluxes affecting the Earth's atmospheric CO_2 pool?
- On a sheet of paper or a sticky note, have students individually answer the exit ticket questions. Depending on time, you may have students answer both questions, assign students to answer a particular question, or let students choose one question to answer. Collect and review the answers.

The conclusions question will provide you with information about what your students are taking away from the activity. Student answers to the conclusions question can be used on the Driving Question Board (if you are using one). The predictions question allows students to begin thinking about the next activity and allows you to assess their current ideas as you prepare for the next activity. Student answers to the predictions question can be used as a lead into the next activity.

Tab 3: Assessment

Check to see if students are making the connection that photosynthesis causes the inorganic pool to shrink and the organic pool to grow, whereas cellular respiration causes the opposite trend. Students might also suggest that photosynthesis causes a "flux" to the biomass pool, and cellular respiration causes a "flux" to the atmosphere pool. In addition, check that students are understanding how combustion contributes to the atmosphere pool and is not balanced by a different flux.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

- Identify locations in the room as the two carbon pools, then have students play the role of carbon atoms moving between the two pools.
- Project the graphs onto a white board and demonstrate how to fill them in after each move.
- Have students work in pairs and fill out one worksheet for each pair.

Modifications (Accordion)

Demonstrate how to use one scenario card with the class before dividing them into pairs or groups to discuss their cards. You may also want to draw circles on the board to represent the biomass (organic) and atmosphere (inorganic) pools that students can use to illustrate the results discussion or ask questions.

Activity 4.4: Global Computer Model (50 min)

Tab 1: Overview and Preparation

Target Student Performance

Students use an online computer model to make quantitative predictions of how changes in photosynthesis, cellular respiration, and combustion fluxes will affect the long-term trend in the atmospheric CO_2 pool.

Resources Provided

- Global Computer Model (http://carbontime.bscs.org/sites/default/files/simulations/HES_Simulation/index.html)
- 4.4 Global Computer Model PPT
- 4.4 Global Computer Model Reading (1 per student)
- 4.4 Global Computer Model Worksheet (1 per student)
- 4.4 Grading Global Computer Model Worksheet

Recurring Resources

- Learning Tracking Tool for Human Energy Systems (1 per student)
- Assessing the Learning Tracking Tool for Human Energy Systems
- Questions, Connections, Questions Student Reading Strategy
- (Optional) Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? (1 per student)
- (Optional) Assessing Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half?

Setup

Prepare one copy of 4.4 Global Computer Model Reading and one copy of 4.4 Global Computer Model Reading for each student. Follow the link for the Global Computer Model short film to download it to your computer. Prepare a computer and projector for the film and 4.4 Global Computer Model PPT. You may want to prepare the poster papers around the room as described in step 4 of the directions.

Tab 2: Directions (accordion for individual steps in directions)

1. Introduce the Activity.

Display Slide 2 of the 4.4 Global Computer Model PPT to show student where they are in the instructional sequence.

2. Revisit Carbon Pools and Fluxes.

Using Slide 3, revisit the three carbon pools in the global carbon cycle. Remind students that carbon can be found in the organic matter pool, inorganic pool and fossil fuel pool. Discuss what carbon might be found in in each pool.

- Display Slide 4 and revisit the three carbon fluxes in the global carbon pool. Recall the processes that move CO_2 into and out of pools.

3. Revisit the long-term trend in the Keeling Curve.

Display Slide 5. Review conclusions made so far about global carbon cycling and about how the Tiny World Model can help explain the annual cycle of the long-term trend of the Keeling Curve.

4. Introduce Goals for Activity 4.4

Display Slide 6 of 4.4 Global Computer Model PPT. Revisit goals from past lessons and tell students that in this lesson they will aim to figure out how to accurately predict future CO_2 concentrations.

5. Introduce the Global Computer Model.

Display Slide 7 of 4.4 Global Computer Model PPT. Tell students that they will be using this online global computer model to help them answer their question of how they can predict future CO_2 concentrations.

Display Slide 8. Point out the various carbon Pools. Show Slide 9 to point out the various fluxes.

6. Reading About Global Pools and Fluxes

Have students take out 4.4 Global Computer Model Reading. Read through the reading, stopping at The Balance Between Photosynthesis and Cellular Respiration section on page 3. Use Slide 10 and/or the Questions, Connections, Questions Reading Strategy. See the Questions, Connections, Questions Reading Strategy Educator Resource document for information about how to engage students with this strategy.

7. Overview of how to use the Global Computer Model

Have students follow the URL to the Global Computer Model(http://carbontime.bscs.org/sites/default/files/simulations/HES_Simulation/index.html). The URL is on Slide 7 of 4.4 Global Computer Model PPT or on page 1 of 4.4 Global Computer Model Reading.

- Display Slide 11 to show students how to change a size of a flux on the Global Computer Model.
- Use Slide 12 to show students how to control when to the disturbance will begin and when the disturbance will end in the Global Computer Model.
- Use Slide 13 to show students how to use the slider to choose a year to view in the results table. Refer to Slide 14 to show students how to read the table on the results page. Point out the year and what each number represents in the table so that they know what to record on their 4.4 Global Computer Model Worksheet.

8. Students Work to Complete Global Computer Model Worksheet

Students work alone or in pairs to complete Runs 1-4 on the Global Computer Model Worksheet using the online Global Computer Model.

9. (Optional) Have Students Compare Results and Discuss Patterns

Using Slides 15-17, have students compare their results and discuss patterns for their runs 1-3 on the 4.4 Global Computer Model Worksheet.

10. Students Read and Answer Remaining Questions

Have students read the final section in 4.4 Global Computer Model Reading, The Balance Between Photosynthesis and Cellular Respiration section, on page 3. Have students write answers to questions on the 4.4 Global Computer Model Worksheet either individually or in pairs.

11. Discuss answers to Run 4 and Questions about Patterns

Using Slide 18, have students discuss answers to Section B of the 4.4 Global Computer Model Worksheet.

12. (Optional) Revisit Earlier Predictions

Display Slide 19, have students revise and discuss their predictions for the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? Use the Assessing the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? to aid in facilitating discussion of ideas.

13. Have a discussion to complete the Learning Tracking Tool for this activity.

Show Slide 20 of the 4.4 Global Computer Model PPT.

- Have students take out their Learning Tracking Tool from the previous lesson.
- Have students write the activity name in the first column, "4.4 Global Computer Model."
- Have a class discussion about what students figured out during the activity that will help them in answering the lesson driving questions:
    - What causes the annual cycle: CO_2 concentrations in Hawaii to go down every summer and up every winter?
    - What causes the long-term trend: CO_2 concentrations to go up every year?
    - How can we predict what will happen to CO_2 concentrations in the future?
- When you come to consensus as a class, have students record the answer in the second column of the tool.
- Have a class discussion about what students are wondering now that will help them move towards answering the unit driving question. Have students record the questions in the third column of the tool.
- Have students keep their Learning Tracking Tool for future activities.
- Example Learning Tracking Tool

Activity	What We Figured Out	What We are Asking Now
Activity 4.4: Global Computer Model	*When the fluxes into and out of living and soil organic matter (photosynthesis and cellular respiration), then the unbalanced flux from fossil fuel combustion increases the size of the atmospheric CO_2 pool.*	*What else affects the size of the Earth's atmospheric CO_2 pool?*

Tab 3: ***Assessment***

This activity includes opportunities for both formative and summative assessment.

- Check for student understanding of the reading using the Questions, Connections, Questions Reading Strategy Educator Resource.
- Use 4.4 Grading Global Computer Model Worksheet to check for student understanding after the activity is over.
- Check for changes in students' predictions and strategies for predicting based on Assessing the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half?
- Compare your students' summaries of what they learned and questions to the suggestions on Assessing the Learning Tracking Tool for Human Energy Systems.

Tips

- You might want to point in step 5 out that although the seasonal cycle is a naturally occurring phenomenon, the current overall trend in increases in CO_2 and temperature cannot be explained using evidence of natural cycles. Students may point to specific natural cycles as evidence that climate change is not caused by humans, which might include sunspots, volcanic activity, El Niño, or changes in the Earth's rotation around the Sun. While it is true that these natural phenomena do cause variations in shorter time periods (1-15 years or so), these variations do not contradict the evidence for the recent increase in CO_2 levels and temperature, especially in the last 60 years. These increases have persisted over a longer time period than natural causes like sunspots and volcanoes can explain.
- It won't hurt to mention a few times that the fossil fuel pool has nothing to do with the seasonal flux.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

- Have students work in pairs, with each pair using one computer and one worksheet.
- Identify locations in the room as the three carbon pools, then have students play the role of carbon atoms moving between the three pools.
- Project the graphs onto a white board and demonstrate how to fill them in after each move.

Modifications (Accordion)

Optional Activity 4.5: Effects of the Seasons and Oceans (50 min)

Tab 1: Overview and Preparation

Target Student Performance

Students use a diagrammatic carbon cycle model to investigate how oceans and seasons in the Northern and Southern Hemispheres affect the annual cycle and a long-term trend in the atmospheric CO_2 pool.

Resources You Provide

- Pump handle video (https://www.esrl.noaa.gov/gmd/ccgg/trends/history.html) See the Lesson 4 Background information for more information about this video.
- Keeling & South Pole PPT slides & video: https://youtu.be/UatUDnFmNTY
- Primary productivity PPT slides & video: http://eoimages.gsfc.nasa.gov/images/globalmaps/data/mov/MOD17A2_M_PSN.mov
- Explanation of how changes in sunlight drive changes in photosynthesis, see https://www.youtube.com/watch?v=WgHmqv_-UbQ
- Website on ocean acidification: https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification
- Media representations of carbon cycle:
    - ESRL: https://www.esrl.noaa.gov/research/themes/carbon/
    - WGBH: http://d3tt741pwxqwm0.cloudfront.net/WGBH/pcep14/pcep14_int_co2cycle/index.html

Resources Provided

- 4.5 Seasons & Oceans PPT
- 4.5 Seasons and Oceans Worksheet (1 per student)
- 4.5 Grading the Seasons and Oceans Worksheet

Recurring Resources

- Learning Tracking Tool for Human Energy Systems (1 per student)
- Assessing the Learning Tracking Tool for Human Energy Systems
- (Optional) Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half? (1 per student)
- (Optional) Assessing Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half?

Setup

Prepare one copy of 4.5 Seasons and Oceans Worksheet and one copy of Big Idea Probe: What Would Happen If We Cut Fossil Fuel Use In Half? for each student. Prepare a computer and projector for the film and 4.5 Seasons & Oceans PPT. You may want to open the videos ahead of time on your computer as they will be shown during this lesson. Make sure students have their Learning Tracking Tool available for the end of the lesson.

Tab 2: ***Directions*** *(accordion for individual steps in directions)*

1. Introduce the Activity. Display Slide 2 of the 4.5 Seasons & Oceans PPT to show students where they are in the instructional sequence.
2. Discuss the goals for this activity Use Slides 3-5 to remind students of the pools and fluxes that they have used in previous models and how they can be used to explain the seasonal patterns and long-term trend in the Keeling Curve. Use Slide 6 to introduce and discuss that two goals for this lesson.
3. Compare data about the annual cycle in the Northern and Southern Hemispheres. Show the NOAA "Pumphandle" video (https://www.esrl.noaa.gov/gmd/ccgg/trends/history.html) Use Slide 7 to lead a discussion of different patterns that they notice in the Northern and Southern Hemispheres. See the Lesson 4 Background information for more information about this video. Use Slide 8 and the associated video (https://www.youtube.com/watch?v=UatUDnFmNTY&feature=youtu.be) to discuss the different annual patterns: • In Hawaii CO_2 concentrations rise to a peak in May, then fall during the Northern Hemisphere summer. • At the South Pole CO_2 concentrations rise to a peak in October, then fall during the Northern Hemisphere winter.
4. Discuss different photosynthesis fluxes in the Northern and Southern Hemispheres. Use Slide 9 to show students how photosynthesis fluxes in the Northern and Southern Hemispheres change across the seasons. Use Slide 10 to have students describe the pattern: • The Northern Hemisphere photosynthesis flux peaks in the Northern Hemisphere summer (around July). • The Southern Hemisphere photosynthesis flux peaks in the Southern Hemisphere summer (around January).
5. Have students write explanations of the global pattern in the annual cycle. Pass out the 4.5 Seasons and Oceans Worksheet. Show Slides 11 and 12 and remind students about how they can use the Four Questions to guide their writing of a good explanation. Show Slide 13 and have students complete Part A of the worksheet before continuing the lesson.
6. Discuss the students' written explanations. Slides 14-18 show correct answers to each of the Four Questions and to each question in Part A of the 4.5 Seasons and Oceans Worksheet. Show these slides and have students check, discuss, and revise their own answers to the worksheet questions.

7. Introduce the Global Carbon Cycling Diagram.

Show Slides 19 to introduce the second goal for this activity: figuring out how other pools and fluxes affect atmospheric CO_2.

Use Slide 20 to elicit students' ideas about other pools and fluxes that are not included in the models that they have been using.

Use Slide 21 to introduce the Global Carbon Cycling Diagram (based on data from the Global Carbon Project: www.carsclimate.com blog.) Note the new pools and fluxes:

- The oceans are the other major pool that was not included in the models used earlier in this lesson. There are fluxes into the ocean (when CO_2 dissolves in water) and out of the ocean (when CO_2 vaporizes from water, like soda water losing its fizz).
- Land use change (such as forests being converted to farms or cities) affects fluxes into and out of vegetation and the soil organic carbon pool.

8. Work with the class to calculate how the atmospheric carbon pool is changing.

Show Slides 22 and 23 to remind students that they can use the rules for pools and fluxes (from Activity 4.3: Tiny World Modeling) to calculate how the atmospheric carbon pool is changing.

After students have tried their calculations, use Slide 24 to show a way to calculate the overall net flux of carbon into the atmosphere.

Slide 25 provides a link to more information about the effects of the carbon flux into the oceans.

9. Use the Global Carbon Cycling Diagram to predict the effects of cutting fossil fuel use in half.

Slide 26 reminds students of the Big Idea probe: What Would Happen If We Cut Fossil Fuel Use In Half? Ask students if they can use the Global Carbon Cycling Diagram to calculate and answer to that question.

Have students complete Part B of 4.5: Seasons and Oceans Worksheet.

Have students check their calculations against those on Slide 28.

10. Have a discussion to complete the Learning Tracking Tool for this activity.

Show Slide 29 of the 4.5 Effects of Seasons and Oceans PPT.

- Have students take out their Learning Tracking Tool from the previous lesson.
- Have students write the activity name in the first column, "4.5 Effects of Seasons and Oceans."
- Have a class discussion about what students figured out during the activity that will help them in answering the lesson driving questions:
  - What causes the annual cycle: CO_2 concentrations in Hawaii to go down every summer and up every winter?
  - What causes the long-term trend: CO_2 concentrations to go up every year?
  - How can we predict what will happen to CO_2 concentrations in the future?
- When you come to consensus as a class, have students record the answer in the second column of the tool.
- Have a class discussion about what students are wondering now that will help them move towards answering the unit driving question. Have students record the questions in the third column of the tool.

- Have students keep their Learning Tracking Tool for future activities.
- Example Learning Tracking Tool

Activity	What We Figured Out	What We are Asking Now
Optional Activity 4.5: Effects of Seasons and Oceans	*The photosynthesis flux changes with the seasons in the Northern and Southern Hemispheres, causing the annual cycle.* *The oceans and change in land use also cause carbon fluxes into and out of the atmosphere.*	*How do humans affect the size of carbon fluxes into and out of the atmosphere?*

Tab 3: Assessment

This activity includes opportunities for both formative and summative assessment.

- Check for student understanding of the reading using the Questions, Connections, Questions Reading Strategy Educator Resource
- Use 4.5 Grading the Seasons and Oceans Worksheet to check for student understanding after the activity is over.
- Check for changes in students' predictions and strategies for predicting based on Assessing the Big Idea Probe: What Would Happen if We Cut Fossil Fuel Use in Half?
- Compare your students' summaries of what they learned and questions to the suggestions on Assessing the Learning Tracking Tool for Human Energy Systems.

Tips

Watch the Pumphandle video a few times to allow students to ask questions and to check for comprehension of the many different components of the video.

Tab 4: Differentiation & Extending the Learning

Differentiation (Accordion)

This is an optional activity that you may skip if you have large numbers of special needs students. The content is interesting, but not essential for a basic understanding of the unit's key goals.

Modifications (Accordion)

Extending the Learning (Accordion)

Have students investigate the effects of ocean acidification: https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification

Discuss other information that students have seen about global carbon cycling and climate change in the media, and how it compares with what they have worked with in this lesson.