

Human Energy Systems Unit Front Matter

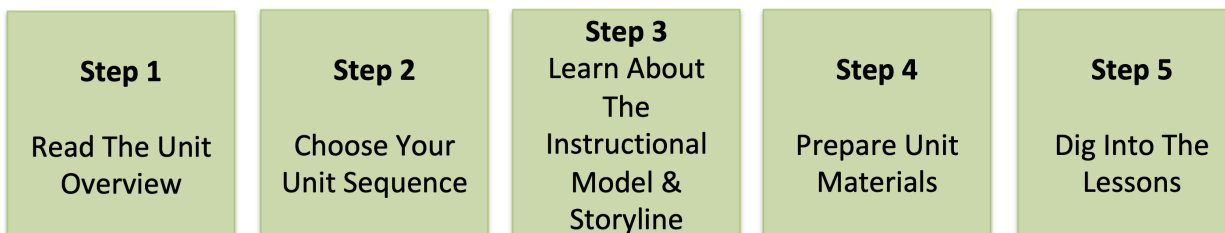
Unit Home

Human Energy Systems is one of the six *Carbon TIME* units. If you are new to teaching *Carbon TIME*, read the [Carbon TIME FAQ: Which Units Should I Teach](#).

Download
PDF of Unit
Front Matter

The *Human Energy Systems Unit* supports students in using core disciplinary ideas, science practices, and cross-cutting concepts to develop scientific explanations of how different energy systems *transform matter and energy*.

Follow these steps to get ready to teach the *Human Energy Systems Unit*



Lead Editor for 2019 Version

Kirsten D. Edwards, Department of Teacher Education, Michigan State University

Principal Authors

Hannah K. Miller, Department of Teacher Education, Northern Vermont University
Wendy Johnson, Department of Teacher Education, Michigan State University
Jenny Dauer, School of Natural Resources, University of Nebraska-Lincoln
Beth Covitt, College of Arts and Sciences, University of Montana
Craig Kohn, Department of Teacher Education, Michigan State University
Bonnie McGill, Kansas Biological Survey, University of Kansas
Charles W. (Andy) Anderson, Department of Teacher Education, Michigan State University

Contributing Authors

Sarah Bodbyl Roels, Elizabeth Xeng de los Santos, Jennifer Doherty, Allison Freed, Bonnie McGill, Lindsey Mohan, Emily Scott, Alex Walus Beth Covitt, Jennifer Doherty, Emily Scott, Nick Verbanic

Illustrations

Craig Douglas



Carbon TIME is licensed under a [Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License](#). You must give appropriate credit and indicate if any changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. You may not use the material for commercial purposes. If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original. As noted within the materials, some

images, videos, and simulations may have different licensing, either more restrictive, or more open than the CC BY-NC-SA license.

This research is supported in part by grants from the National Science Foundation: A Learning Progression-based System for Promoting Understanding of Carbon-transforming Processes (DRL 1020187) and Sustaining Responsive and Rigorous Teaching Based on *Carbon TIME* (NSF 1440988). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or the United States Department of Energy.

This unit is also available online at <http://carbontime.bsccs.org/>. Contact the MSU Environmental Literacy Program for more information: EnvLit@msu.edu.

Overview

The goal of the *Human Energy Systems* unit is to introduce students to carbon cycling at a global scale and the implications of human fossil fuel use for climate change. Students:

Download
PDF of Unit
Overview

- Investigate patterns of change in Earth systems (global temperatures, global sea levels, Arctic sea ice, atmospheric CO₂) and use the Greenhouse Effect to explain how increases in greenhouse gas concentrations drive changes in other systems;
- Explain how three key fluxes (photosynthesis, cellular respiration, combustion of fossil fuels) affect the atmospheric CO₂ pool;
- Explain how human actions affect CO₂ fluxes; and
- Predict effects of changes in human actions on the atmospheric CO₂ pool.

The Research Base

Carbon is the key! In the unit, students learn to tell the story of how matter and energy are transformed as they move through human energy systems. A particularly powerful strategy for explaining how Earth systems transform matter and energy involves *tracing carbon atoms*. For more information about the *Next Generation Science Standards* **disciplinary core ideas** included in this unit see the sections on the Large Scale Four Questions below and the [Unit Goals](#).

Research base. This unit is based on [learning progression research](#) that describes the resources that students bring to learning about human energy systems and the barriers to understanding that they must overcome. It is organized around an [instructional model](#) that engages students in three-dimensional practices.

Students' Roles and Science Practices

Human Energy Systems is the culminating unit in the *Carbon TIME* sequence, focusing on global-scale phenomena: climate change and global carbon cycling. We recommend that teachers complete the *Systems & Scale*, *Plants*, and *Ecosystems* units before the *Human Energy Systems* unit if possible. The foundational knowledge introduced in these units helps prepare students to engage in conversations and activities that require a basic understanding of photosynthesis, cellular respiration, and combustion of fossil fuels (on a cellular or atomic-molecular scale) and apply these concepts to carbon cycling and energy flow (on a global scale). It is through examining the pools and fluxes of carbon at a global scale that students will be able to make connections between energy use, combustion of fossil fuels, carbon emissions, and climate change.

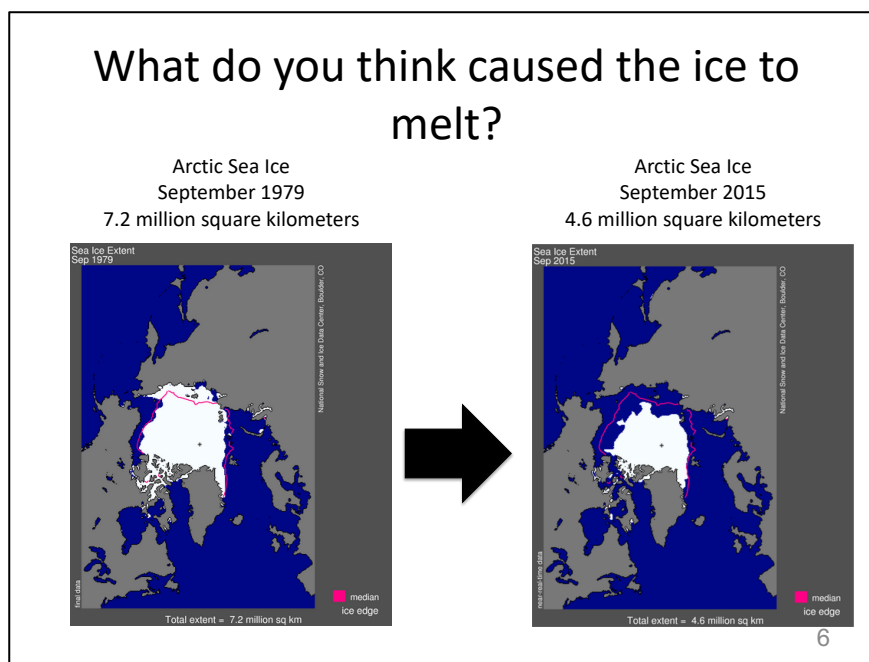
The [Instructional Model](#) reflects the two phases of the unit. The first phase focuses on helping students to understand, analyze, and explain multiple phenomena associated with

climate change (What is happening to the planet?). The second phase focuses on global carbon cycling (What causes changes in CO₂?). In each phase students practice the roles of questioner, investigator, and explainer.

Phase 1: What is happening to the planet? (climate change)

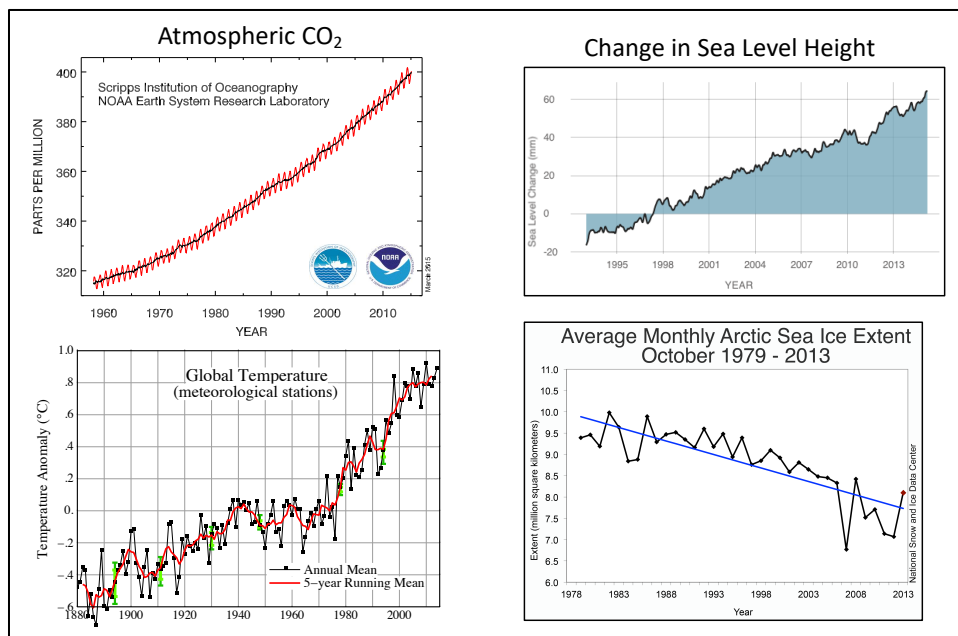
In Lessons 1-3 students question, investigate, and explain four phenomena associated with climate change: Arctic sea ice, global sea levels, global average temperatures, and atmospheric CO₂ concentrations.

Lesson 1: After taking the unit pretest, students begin by expressing their ideas and questions around a single phenomenon: Arctic sea ice. They begin with ideas and questions about a single pair of images, comparing the extent of Arctic sea ice in 1979 and 2016. They then investigate data on Arctic sea ice over multiple years, learning to make graphs that show two patterns: (a) the extent of ice varies unpredictably from one year to the next, and (b) there is a long-term trend toward reduced ice cover.



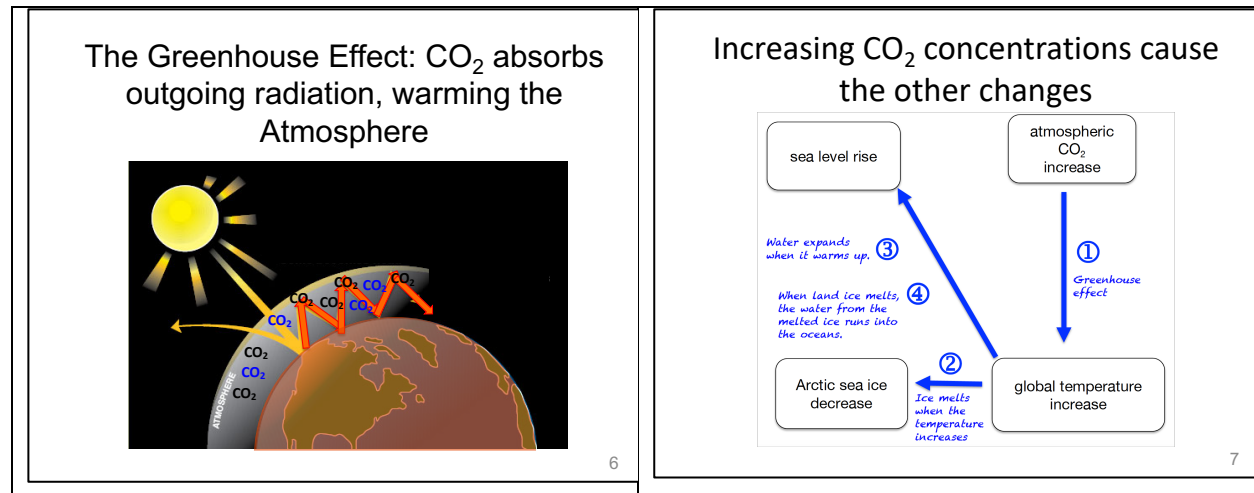
Lesson 2: Students investigate multiple representations of data about three other phenomena, comparing the representations to look for patterns in the data. They end the lesson with four clear long-term trends:

- The extent of Arctic sea ice is decreasing



- Sea levels are rising
- Global average temperatures are rising
- Global concentrations of CO₂ are rising

Lesson 3: Students learn about the Greenhouse effect and use it to explain the connections among the long-term trends: Increasing CO₂ levels are causing increases in global temperatures; the increasing temperatures are causing sea level to rise and ice to melt. Thus, atmospheric CO₂ is the driver—the factor that causes change in the other variables.



Phase 2: What causes changes in CO₂? (global carbon cycling)

In the second half of the unit students investigate and explain “what drives the driver”—what is causing changes in atmospheric CO₂ levels.

Lesson 4: Students begin by sharing questions and hypotheses and make predictions about how reducing fossil fuel use will affect atmospheric CO₂ using the Big Ideas Probe. Students figure out how to answer the driving question by tracing carbon-containing molecules through a series of movements and chemical changes as they travel through different matter pools in Earth systems. At each stage in these processes they answer **Four Questions** about what is happening: The *Carbon Pools Question*, the *Carbon Cycling Question*, the *Energy Flow Question*, and the *Stability and Change Question*.

Note that, in *Carbon TIME*, NGSS **crosscutting concepts** serve as the “rules of grammar” for producing a scientific performance. With respect to bread molding, high quality explanations should attend to the following rules that are implied by crosscutting concepts. Explanations should attend to:

- *Scale* by explaining events and phenomena at the appropriate scale (see more in the structure and function bullets below).
- *Systems and system models and energy and matter* by following rules for tracing matter and energy through systems and system models. For example, neither energy nor matter should be created or destroyed as it moves into, through, or out of a system.
- *Structure and function* by linking structures and functions in explanations at each scale.
 - Global scale (tracing fluxes of carbon and energy through different global carbon pools)
 - Macroscopic scale (tracing matter and energy through processes occurring inside plants, animals, and decomposers)

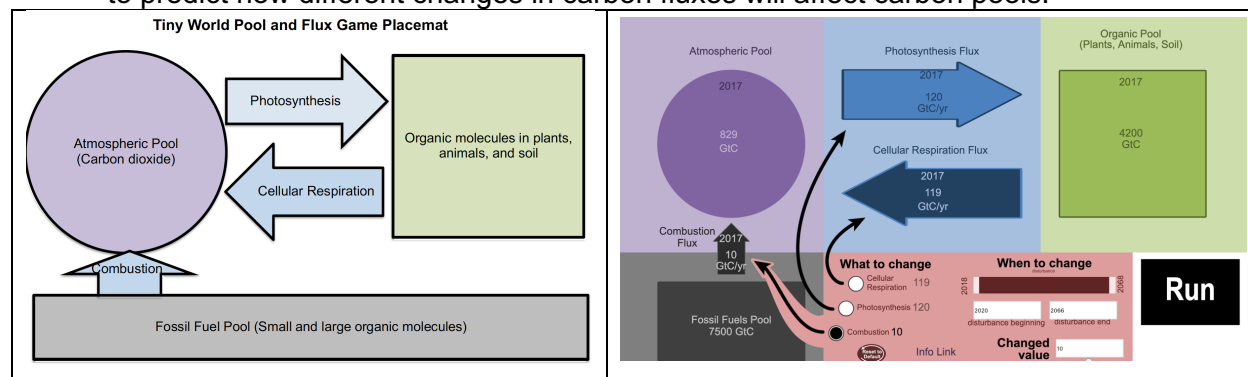
- Atomic-molecular scale (tracing matter and energy through chemical processes—digestion, cellular respiration, and biosynthesis—involving molecules with different structures and properties)

In particular, students should learn to answer the Four Questions in three important contexts:

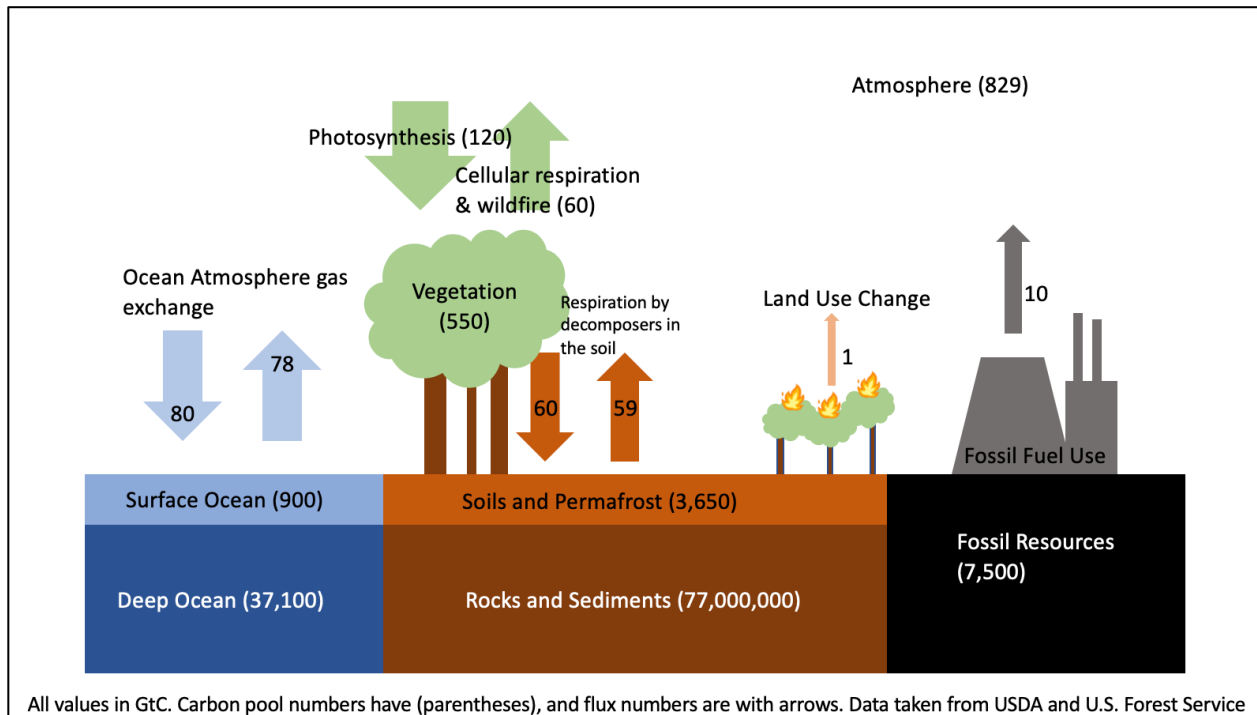
1. At the macroscopic scale, they relate our economic activities and lifestyle choices to carbon-transforming processes, especially combustion of fossil fuels. Students should understand both activities that directly use fossil fuels (such as driving a car) and activities that indirectly use fossil fuels (such as using electrical appliances or buying products that require fossil fuels for manufacture and transportation).
2. Relating local systems, actions, and choices to global effects and outcomes, particularly increasing concentrations of carbon dioxide in the atmosphere.
3. Relating changes in global carbon pools (the atmosphere, biomass, soil organic carbon, and organic carbon in fossil fuels) to the balance of fluxes of carbon between these pools.

Students use three different kinds of pool-and-flux models to explain both the annual cycle and the long-term trend in CO₂ concentrations:

- The Tiny World Game (Activity 4.3) is a hands-on activity in which students move counters to investigate the effect of different balances among photosynthesis, cellular respiration, and combustion fluxes on atmospheric, environmental organic carbon, and fossil fuel pools.
- The Global Carbon Model (Activity 4.4) is an online model that students can manipulate to predict how different changes in carbon fluxes will affect carbon pools.



- The Global Carbon Cycling Diagram (Optional Activity 4.5) adds the oceans as another carbon pool. Students make predictions that include carbon fluxes into and out of the oceans using the diagram.



Lesson 5: Students learn from Lesson 4 that combustion of fossil fuels is the unbalanced flux that drives the continuing increase in atmospheric CO₂ concentrations (and therefore climate change). In Lesson 5 they explore how human activities, including their own lifestyles, depend on combustion of fossil fuels—often in hidden ways. Students investigate how lifestyles associated with different countries (United States, France, China, and Ethiopia) lead to vastly different rates of fossil fuel combustion. They also examine how their own everyday activities (e.g., buying a pizza, washing dishes) use energy from fossil fuels and changes that could reduce carbon emissions.

Lesson 6: The unit concludes with a series of activities in which students make projections of how different scenarios will affect global temperatures as atmospheric CO₂ concentrations. They use a computer to make projections, then discuss different scenarios for Earth's future, and how those scenarios will affect their lives.

Science Literacy

A note on media literacy. This unit makes extensive use of data and models from authoritative sources. Its contents are not scientifically controversial and are consistent with the *Next Generation Science Standards*. The data and models in this unit are complex, but critically important. The unit has many scaffolds, including the [Questions-Connections-Questions](#) reading strategy, to scaffold students' understanding.

Some students might respond to the material presented in this unit by offering conflicting claims they have heard about climate change from their families, friends, or the media. Footnotes are included throughout the Teacher's Guide to help you respond to these claims using with the evidence the scientific community looks to interpret these conflicting claims.


Although scientists view climate change as a matter of scientific evidence and not one of morals and values, the students may feel that their core values and viewpoints are being threatened, which could in turn cause them to disengage. The footnotes included in this unit are intended to provide additional perspectives you might use to help your students interpret the claims they are making in light of the available evidence for anthropogenic climate change.

While we want to encourage students to ask questions and engage in dialogue about the conflicting claims about climate change, we also want to encourage these conversations to be constrained by accurate scientific evidence. Look for footnotes throughout the Teacher's Guide—these are designed to help you navigate these conversations if they arise.

How much detail? There are more complicated and more scientifically accurate ways of talking about chemical bonds and about changes in energy; we discuss some of those in detail in our educator resource: [Carbon TIME Content Simplifications](#). But our [learning progression research](#) has shown that there is an important tradeoff here—many students get lost in the details and never learn a basic coherent story that answers the driving question. The *Next Generation Science Standards* take a clear position on this tradeoff; a coherent story based on principles such as matter and energy conservation are more important than the details. Consult the [Unit Sequence](#) tab and the sections on Extending the Learning at the end of each Activity page to decide how much detail is appropriate for your students.


Unit Sequence

Before beginning the *Human Energy Systems* unit, you need to decide what to teach and importantly, what not to teach! Use this page to choose the unit sequence that's most appropriate for your students.

Other activities are TWO-TURTLE ACTIVITIES (), which place a higher demand on students. Decide whether the higher demand required by these activities will be useful or distracting for *your students*. The [Carbon TIME Turtle Trails](#) document provides further info about choices for making units more or less demanding, depending on your students' needs.

Unless otherwise noted in the table below, all activities in the unit should be taught.

Lesson	Activity Sequence	Feature	Make a Decision
1 (3 hours, 5 min)	1.1: Human Energy Systems Unit Pretest (20 min)		
	1.2: Expressing Ideas and Questions about Arctic Sea Ice (40 min)		
	1.3: Graphic Arctic Sea Ice (45 min)		Activities 1.3, 1.4, and 1.5 engage students in making graphs and constructing trend lines for climate data (in this case Arctic sea ice). If your students are mathematically adept, you could skip these activities and work with them on Arctic sea ice data in Activity 2.1.
	1.4: Drawing a Trend Line (40 min)		
	1.5: Finding a Trend in Arctic Sea Ice (40 min)		
2 (3 hours)	2.1: Home Groups: Four Considerations for Large-Scale Data (45 min)		All students should complete Lesson 2.

	2.2: Expert Groups: Analysis of Large-Scale Data (45 min)		
	2.3: Home Groups: Share Expertise (60 min)		
	2.4: Evidence-Based Arguments for Patterns in Earth Systems		
3 (1 hour, 25 min)	3.1: Millions of Flasks of Air (25 min)		
	3.2: The Greenhouse Effect Reading & Simulation (20 min)		The PhET simulation (https://phet.colorado.edu/en/simulation/greenhouse) for Activity 3.2 needs to be downloaded before students can use it.
	3.3: Relationships between Earth Systems (40 min)		
4 (2 hours, 45 min, + 50 min optional)	4.1: Questions for this Lesson (30 min)		If students have not previously completed the <i>Ecosystems Unit</i> , consider having them complete the simpler version of Tiny World Modeling in <i>Ecosystems Unit</i> Activity 4.1 before completing <i>Human Energy Systems Unit</i> Activity 4.3 which adds the fossil fuel pool and the combustion flux.
	4.2: Carbon Pools and Fossil Fuels (35 min)		
	4.3: Tiny World Modeling (50 min)		
	4.4: Global Computer Model (50 min)		
	Optional Activity 4.5 Effects of Seasons and Oceans		Activity 4.5 allows students to consider the effects of the seasons and oceans on carbon dioxide in the atmosphere. Decide if you will teach this more advanced two-turtle activity.
5 (3 hours)	5.1: Extreme Makeover: Lifestyle Edition (45 min)		All students should complete Lesson 5.
	5.2: Carbon Emissions Jigsaw (60 min)		
	5.3: Energy Scenarios (30 min)		
	5.4: Strategies for Lowering Carbon Emissions (45 min)		
6 (1 hour, 40 min)	6.1: Using Models to Predict Future Conditions (50 min)		All students should complete Lesson 6.
	6.2: How Our Decisions Affect Earth's Future (30 min)		The computer model in Activity 6.2 has some functions similar to those of the computer model in Activity 4.4. Both enable projections of future CO ₂ concentrations. The model in Activity 6.2 also includes temperature projections.
	6.3: Human Energy Systems Unit Posttest (20 min)		

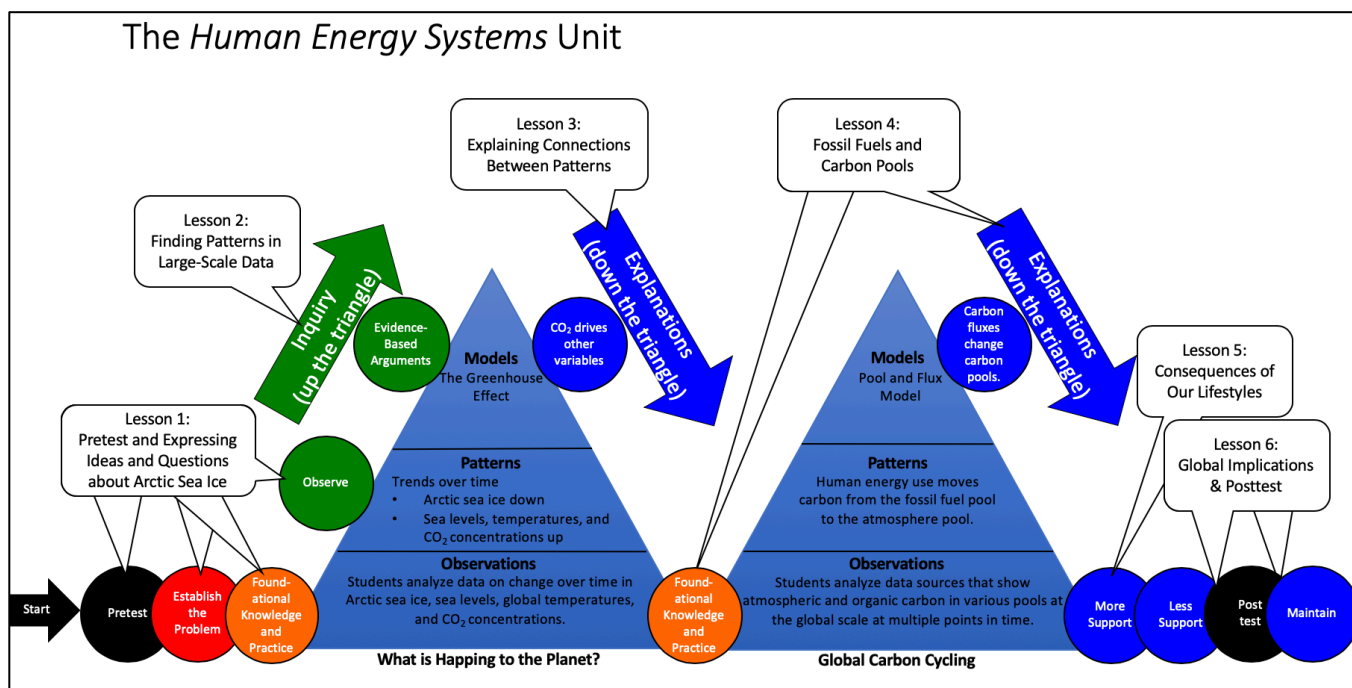
IM & Storyline

Here, we present two ways to think about how lessons are sequenced in the *Human Energy Systems Unit*. The Instructional Model, immediately below, emphasizes how students take on roles of questioner, investigator, and explainer to learn and apply scientific models in each section of the unit. Further below, the Unit Storyline Chart highlights the central question, activity, and answer that students engage with in each lesson of the *Human Energy Systems Unit*.

Instructional Model

Like all *Carbon TIME* units, this unit follows an instructional model (IM) designed to support teaching that helps students achieve mastery at answering the driving question through use of disciplinary content, science practices, and crosscutting concepts. To learn more about this design, see the [Carbon TIME Instructional Model](#).

The instructional model for the *Human Energy Systems Unit* includes two phases, described in the [Unit Overview](#), in which students play the role of questioners, investigators, and explainers. The first phase focuses on helping students to understand, analyze, and explain multiple phenomena associated with climate change (What is happening to the planet?). The second phase focuses on global carbon cycling (What causes changes in CO₂?). Across the unit, classroom discourse is a necessary part of three-dimensional *Carbon TIME* learning. The [Carbon TIME Discourse Routine](#) document provides guidance for scaffolding this discourse in lessons.

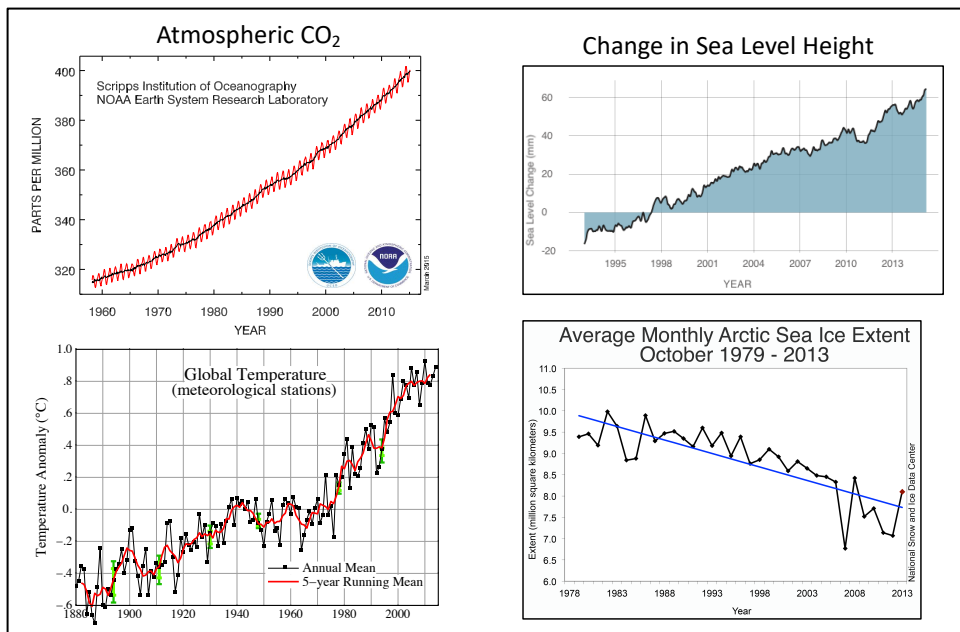


The core of the *Carbon TIME* Instructional Model is the Observation, Patterns, Models (OPM) triangle, which summarizes key aspects to be attended to as the class engages in unit inquiry and explanation. The OPM triangle for the *Human Energy Systems Unit*, shown below, articulates the key observations students make during the unit investigation, the key patterns they identify through analyzing their investigation data, and the central scientific model that can be used to answer the unit's driving question.

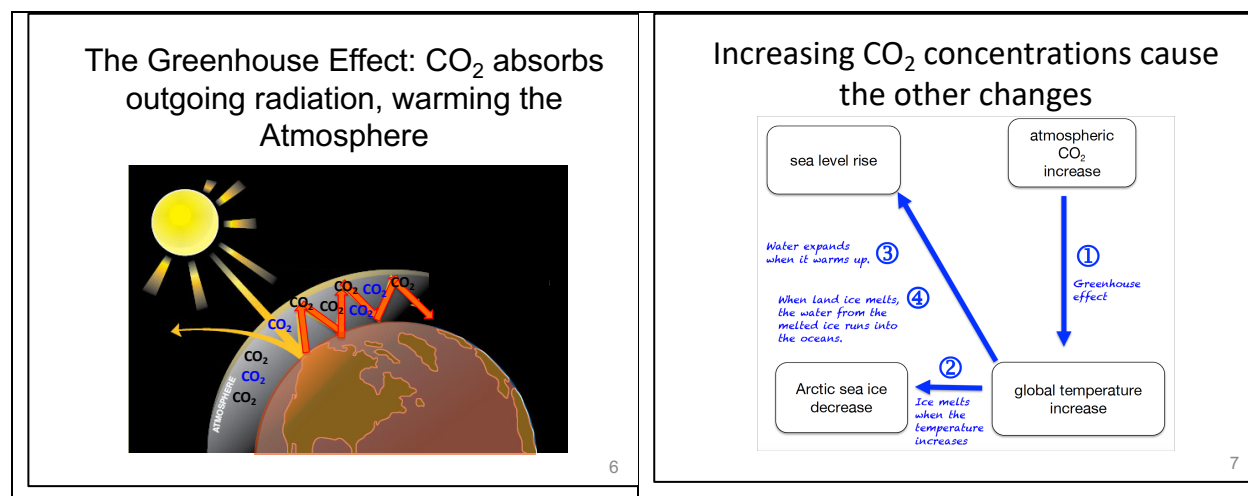
Observations, Patterns, and Models for Phase 1: Climate Change

Observations and patterns: trends in global climate data. Students investigate multiple representations of data about four global phenomena, comparing the representations to look for patterns in the data. They end the Lesson 2 with four clear long-term trends:

- The extent of Arctic sea ice is decreasing
- Sea levels are rising
- Global average temperatures are rising
- Global concentrations of CO₂ are rising



Models: The Greenhouse Effect and CO₂ as the driver. Students learn to use the Greenhouse effect to explain the connections among the long-term trends: Increasing CO₂ levels are causing increases in global temperatures; the increasing temperatures are causing sea level to rise and ice to melt. Thus, atmospheric CO₂ is the driver—the factor that causes change in the other variables.



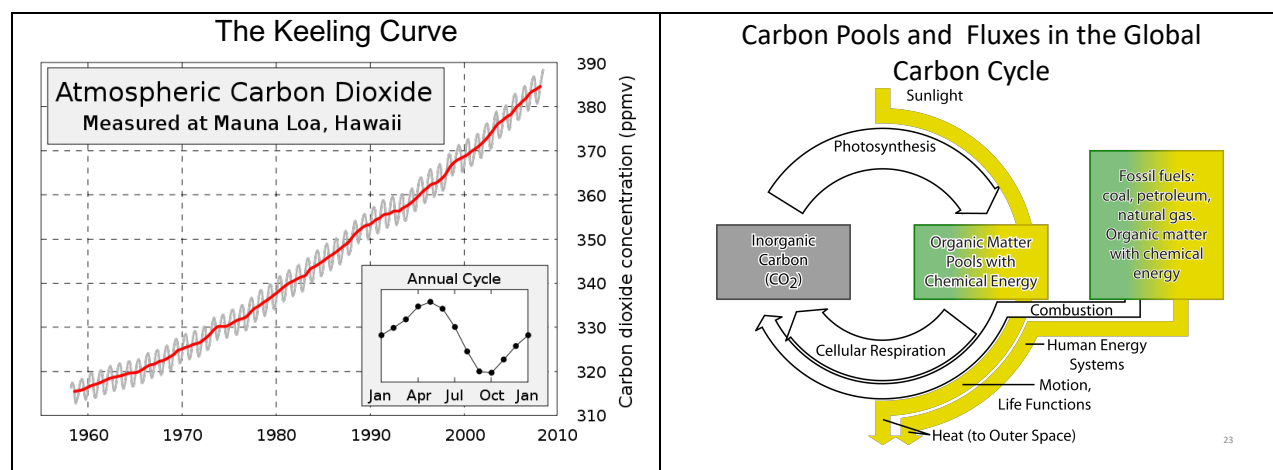
Observations, Patterns, and Models for Phase 2: Global Carbon Cycling

Observations and patterns: Students use visualizations and graphs to investigate changes in atmospheric CO₂ concentrations. Key patterns include:

- The annual cycle: CO₂ concentrations in the northern hemisphere decline every summer and rise every winter.
- The long-term trend: Global CO₂ concentrations have increased from about 310 to 400 ppm since the late 1950s.

Models (and Explanations): Students explain carbon cycling and energy flow between carbon pools by connecting global, macroscopic, and atomic-molecular scales, and answering the Four Questions:

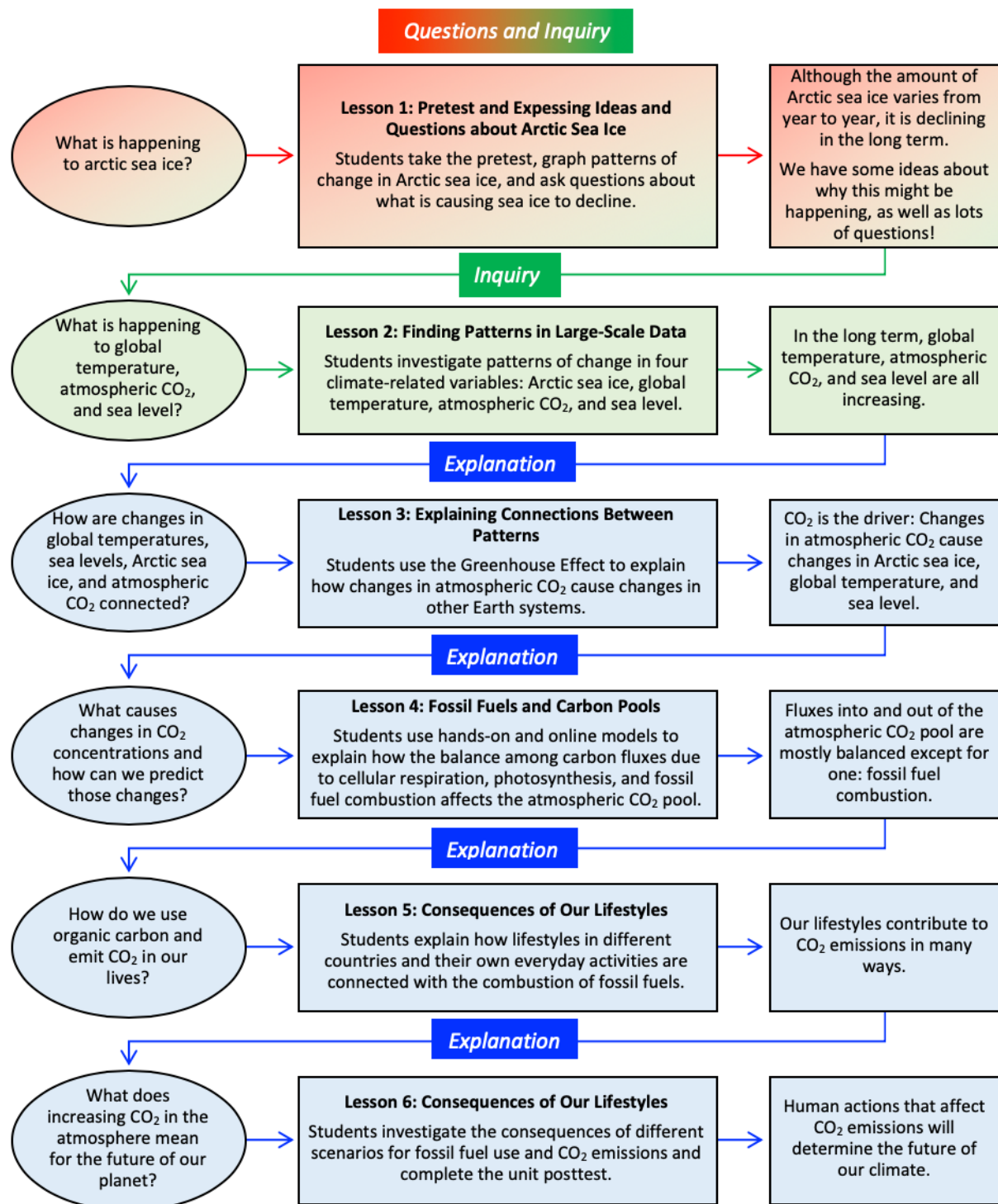
- **Carbon Pools:** carbon atoms are found in CO₂, living organisms, soil organic carbon, oceans, and fossil fuels
- **Carbon Fluxes:** Changes in photosynthesis drive the annual cycle; combustion of fossil fuels drives the long-term trend.
- **Energy Flow:** CO₂ and other greenhouse gases cause climate change.
- **Stability and Change:** The photosynthesis and cellular respiration fluxes are large, but balanced. So, the smaller but unbalanced flux from combustion of fossil fuels is steadily increasing the size of the atmospheric CO₂ pool.



Unit Storyline Chart

Another way to familiarize yourself with the sequence of lessons in the *Human Energy Systems* Unit is with the Unit Storyline Chart depicted below. The Unit Storyline Chart summarizes a unit phenomenon-based driving question associated with each lesson, what classes will do in each lesson to address the question, what conclusions they will come to, and how they will transition to a subsequent lesson.

Download PDF
of Unit IM and
Storyline Chart



Unit Goals

The tables below show goals for this unit in two forms. A table showing specific target performances for each activity is followed by a list of the *Next Generation Science Standards* (NGSS) addressed by this unit.

Target Performances for Each Activity

All *Carbon TIME* units are organized around a common purpose: *assessing and scaffolding students' three-dimensional engagement with phenomena*. Every *Carbon TIME* activity has its specific expectation for students' three-dimensional engagement with phenomena, what we call its **target performance**. Each activity also includes tools and strategies that teachers can use to assess and scaffold the target performance in rigorous and responsive ways.

Download PDF
of Unit Target
Performances

The target performances for each activity in the *Human Energy Systems* unit are listed in the table below.

Activity	Target Performance
<i>Lesson 1 – Pretest and Expressing Ideas about Arctic Sea Ice (students as questioners and investigators)</i>	
Activity 1.1 Human Energy Systems Unit Pretest (20 min)	Students show their initial proficiencies for the overall unit goals: 1. Questioning, investigating, and explaining how the Earth's climate is changing 2. Explaining and predicting how carbon cycles and energy flows in Earth systems.
Activity 1.2: Expressing Ideas and Questions about Arctic Sea Ice (40 min)	Students express ideas and record questions about why Arctic sea ice seems to be shrinking.
Activity 1.3: Graphing Arctic Sea Ice (45 min)	Students use data on Arctic sea ice to construct graphs showing patterns in changing coverage over time.
Activity 1.4: Drawing a Trend Line (40 min)	Students use multi-year averages to construct a trend line using data on Lake Superior ice cover.
Activity 1.5: Finding a Trend in Arctic Sea Ice Data (40 min)	Students use multi-year averages to construct a trend line using data on Arctic sea ice.
<i>Lesson 2 – Finding Patterns in Large Scale Data (students as investigators)</i>	
Activity 2.1: Home Groups: Four Considerations for Large Scale Data (45 min)	Students in home groups express initial ideas about patterns and changes over time for four variables in Earth systems: global temperatures, global sea levels, Arctic sea ice, and atmospheric CO ₂ concentrations.

Activity	Target Performance
Activity 2.2: Expert Groups: Analysis of Large-Scale Data (45 min)	Students in expert groups investigate multiple representations of the four variables in and the Earth systems that they measure, generating explanations and questions.
Activity 2.3: Home Groups: Share Expertise (60 min)	Students return to home groups and share their expertise about patterns of change for four variables in Earth systems: global temperatures, global sea levels, Arctic sea ice, and atmospheric CO ₂ concentrations.
Activity 2.4: Evidence-Based Argument for Earth Systems (30 min)	Students compare patterns of change for the four Earth systems variables and record questions about what causes the patterns and how the patterns are related to one another.
<i>Lesson 3 – Explaining Connections between Patterns (students as explainers)</i>	
Activity 3.1: Millions of Flasks of Air (25 min)	Students explain why Charles David Keeling went to Hawaii to collect data on atmospheric CO ₂ concentrations and how he made his measurements.
Activity 3.2: The Greenhouse Effect (20 min)	Students use a computer simulation to explain how carbon dioxide absorbs visible light and emits infrared radiation—the Greenhouse Effect.
Activity 3.3: Explaining Relationships Between Earth Systems (40 min)	Students use the Greenhouse Effect to explain how atmospheric CO ₂ concentration is the driver that causes changes in other Earth systems.
<i>Lesson 4 – Fossil Fuels and Carbon Pools (students as questioners, investigators, and explainers)</i>	
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	Target Performance
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.
<i>Lesson 5 – Consequences of Our Lifestyles (students as explainers)</i>	
Activity 5.1 Extreme Makeover: Lifestyle Edition (45 min)	Students choose preferred lifestyles based on data about four countries (United States, France, China, Ethiopia) and compare CO ₂ emissions based on those lifestyles.
Activity 5.2 Carbon Emissions Jigsaw (60 min)	Students explain the mechanisms through which human activities and technologies in four different areas (electricity, transportation, buildings, food) lead to CO ₂ emissions.
Activity 5.3 Energy Scenarios (30 min)	Students explain how different personal activities (energy scenarios) lead to CO ₂ emissions.
Activity 5.4 Strategies for Lowering Carbon Emissions (45 min)	Students create and share posters explaining strategies for reducing CO ₂ emissions.
<i>Lesson 6 – Global Implications and Posttest (students as explainers and predictors)</i>	
Activity 6.1 Using Models to Predict Future Conditions (50 min)	Students use the online Very, Very Simple Climate Model to make predictions about future atmospheric CO ₂ concentrations and global temperatures based on CO ₂ emissions scenarios.
Activity 6.2 How Our Decisions Affect Earth's Future (30 min)	Students use graphs of projections from computer models to consider the impacts of increasing atmospheric CO ₂ on Earth's systems and on living things.
Activity 6.3: Human Energy Systems Unit Posttest (20 min)	Students show their initial proficiencies for the overall unit goals: <ol style="list-style-type: none"> 1. Questioning, investigating, and explaining how the Earth's climate is changing 2. Explaining and predicting how carbon cycles and energy flows in Earth systems.

Next Generation Science Standards

The *Next Generation Science Standards* (NGSS) performance expectations that middle and high school students can achieve through completing the *Human Energy Systems* Unit are listed below. To read a discussion of how the *Carbon TIME* project is designed to help students achieve the performances represented in the NGSS, please see [Three-dimensional Learning in Carbon TIME](#).

High School

- Matter and Its Interactions. HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
<http://www.nextgenscience.org/hsp1-matter-interactions>
- 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.
<http://www.nextgenscience.org/hsls2-ecosystems-interactions-energy-dynamics>
- Ecosystems: Interactions, Energy, and Dynamics. HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- 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.
<http://www.nextgenscience.org/hsls2-ecosystems-interactions-energy-dynamics>
- Earth's Systems. HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
<http://www.nextgenscience.org/hsess-es-earth-systems>
- Earth and Human Activity. HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
<http://www.nextgenscience.org/hsess3-earth-human-activity>
- 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.
<http://www.nextgenscience.org/hsess3-earth-human-activity>
- 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.
<http://www.nextgenscience.org/hsess3-earth-human-activity>

Middle School

- MS-ESS2-1. Develop a model to describe the cycling of the Earth's materials and the flow of energy that drives this process.
- Earth and Human Activity. MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
<http://www.nextgenscience.org/msess3-earth-human-activity>
- 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.
<http://www.nextgenscience.org/msess-hi-human-impacts>

- 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.
<http://www.nextgenscience.org/msess3-earth-human-activity>

Materials

Recurring Resources

- Engaging Students with Readings and the Questions, Connections, Questions Reading Strategy Educator Resource
- Questions, Connections, Questions Student Reading Strategy
- Four Questions 11 x 17 Poster
- Four Questions Handout with Checklist
- Using Big Idea Probes
- (Optional) Big Idea Probe Fossil Fuel Half: What Would Happen if We Cut Fossil Fuel Use in Half?
- (Optional) Assessing Big Idea Probe Fossil Fuel Half: What Would Happen if We Cut Fossil Fuel Use in Half?
- Learning Tracking Tool for Human Energy Systems
- Assessing the Learning Tracking Tool for Human Energy Systems

Resources You Provide

Activity 1.1: Human Energy Systems Unit Pretest (20 min)

- pencils (1 per student, for paper version)
- computer with an Internet connection (1 per student, for online version)

Activity 1.2: Expressing Ideas about Arctic Sea Ice (40 min)

- sticky notes (1 per student)
- (Optional) Powers of Ten Video (<http://www.youtube.com/watch?v=0fKBhvDjuy0>)

Activity 1.3: Graphing Arctic Sea Ice (45 min)

- Pencil (1 per student)

Activity 1.4 Drawing a Trend Line (40 min)

- 1.3 Graphing Arctic Sea Ice Worksheet (completed worksheets from previous activity)

Activity 1.5: Finding a Trend in Arctic Sea Ice Data (40 min)

- 1.3 Graphing Arctic Sea Ice Worksheet (completed worksheets from Activity 1.3)

Activity 2.2: Expert Groups: Analysis of Large-Scale Data (45 min)

- Jigsaw Cards (already distributed during previous activity)

Activity 2.3: Home Groups: Share Expertise (60 min)

- 2.1 Finding Patterns Tool for Earth Systems (from previous activity)
- 2.1 Assessing the Finding Patterns Tool for Earth Systems

Activity 2.4: Finding Patterns in Earth Systems (30 min)

- 2.1 Finding Patterns Tool for Earth Systems (completed from previous activity)

Activity 4.1: Questions for this Lesson (30 min)

- [Explaining Relationships Between Earth Systems Worksheet](#) (completed from Lesson 3)

Activity 4.3: Tiny World Modeling (50 min)

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

Activity 4.4: Global Computer Model (50 min)

- Computers (1 for each student or each pair of students)

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

- 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

Activity 5.1 Extreme Makeover: Lifestyle Edition (45 min)

- (optional) Calculator (1 per group of four students)

Activity 5.2: Carbon Emissions Jigsaw (60 min)

- (From previous lesson) [5.1 Lifestyle Cards](#) (1-2 sets per class)
- (From previous lesson) [5.1 Extreme Makeover Lifestyle Edition Worksheet](#) (1 per student)
- (From previous lesson) [5.1 Secrets Revealed! Worksheet](#) (1 per student)

Activity 5.4: Strategies for Lowering Carbon Emissions (45 min)

- Chart paper (1 per group of four students)

Activity 6.3: Human Energy Systems Unit Posttest (20 min)

- pencils (1 per student, for paper version)

Resources Available on the Website

Activity 1.1: Human Energy Systems Unit Pretest (20 min)

- [1.1 Human Energy Systems Unit Pretest](#) (1 per student or online)
- [1.1 Assessing the Human Energy Systems Unit Pretest](#)

Activity 1.2: Expressing Ideas about Arctic Sea Ice (40 min)

- [1.2 Expressing Ideas and Questions about Arctic Sea Ice PPT](#)
- [1.2 Expressing Ideas and Questions Tool for Arctic Sea Ice](#) (1 per student)
- [1.2 Assessing the Expressing Ideas and Questions Tool for Arctic Sea Ice](#)

- 1.2 Human Energy Systems Storyline Reading: Learning from the Work of an Atmospheric Chemist (1 per student)

Activity 1.3: Graphing Arctic Sea Ice (45 min)

- 1.3 Graphing Arctic Sea Ice PPT
- 1.3 Graphing Arctic Sea Ice Worksheet
- 1.3 Grading the Graphing Arctic Sea Ice Worksheet
- Website to retrieve data: http://nsidc.org/data/seaice_index/archives/image_select

Activity 1.4: Drawing a Trend Line (40 min)

- 1.4 Drawing a Trend Line PPT
- 1.4 Drawing a Trend Line Worksheet
- 1.4 Grading the Drawing a Trend Line Worksheet

Activity 1.5: Finding a Trend in Arctic Sea Ice Data (40 min)

- 1.5 Finding a Trend in Arctic Sea Ice PPT
- 1.5 Finding a Trend in Arctic Sea Ice Worksheet
- 1.5 Grading the Finding a Trend in Arctic Sea Ice Worksheet
- Arctic Sea Ice Video: <https://www.youtube.com/watch?v=FDRnH48LvHQ>

Activity 2.1: Home Groups: Four Considerations for Large Scale Data (45 min)

- 5.4 Strategies for Lowering Carbon Emissions PPT
- Arctic Sea Ice Video: <https://www.youtube.com/watch?v=c6jX9URzZWg>
- 2.1 Finding Patterns Tool for Earth Systems
- 2.1 Assessing the Finding Patterns Tool for Earth Systems
- Jigsaw Cards

Activity 2.2: Expert Groups: Analysis of Large-Scale Data (45 min)

- 2.2 Expert Group A Worksheet (1 per student in Group A)
- 2.2 Expert Group B Worksheet (1 per student in Group B)
- 2.2 Expert Group C Worksheet (1 per student in Group C)
- 2.2 Expert Group D Worksheet (1 per student in Group D)
- 2.2 Assessing Expert Group A Worksheet (1 per class)
- 2.2 Assessing Expert Group B Worksheet (1 per class)
- 2.2 Assessing Expert Group C Worksheet (1 per class)
- 2.2 Assessing Expert Group D Worksheet (1 per class)

Activity 2.3: Home Groups: Share Expertise (60 min)

- 2.3 Home Groups: Share Expertise PPT

Activity 2.4: Finding Patterns in Earth Systems (30 min)

- 2.4 Identifying Patterns in Large Scale Data PPT

Activity 3.1: Millions of Flasks of Air (25 min)

- 3.1 Millions of Flasks of Air Reading (1 per student)
- (Optional) "Climate Change is Clear Atop Mauna Loa" a 12-minute radio story about climate change: <http://www.npr.org/templates/story/story.php?storyId=9885767>

Activity 3.2: The Greenhouse Effect (20 min)

- 3.2 The Greenhouse Effect Reading
- 3.2 The Greenhouse Effect Simulation Worksheet
- 3.2 Grading The Greenhouse Effect Simulation Worksheet
- Optional data (“Global Warming’s Six Americas”) of attitudes toward climate change: <http://www.americanprogress.org/issues/green/reports/2009/05/19/6042/global-warmings-six-americas/>

Activity 3.3: Explaining Relationships Between Earth Systems (40 min)

- 3.3 Explaining Relationships Between Earth Systems Worksheet
- 3.3 Grading the Explaining Relationships Between Earth Systems Worksheet

Activity 4.1: Questions for this Lesson (30 min)

- 4.1 Questions for the Lesson PPT
- (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
- (Extending the learning) *New York Times* Keeling article: <https://nyti.ms/2jCmhVE>

Activity 4.2: Carbon Pools and Fossil Fuels (35 min)

- 4.2 Carbon Pools and Fossil Fuels PPT
- 4.2 Carbon Pools and Fossil Fuels Reading (1 per student)
- Time-lapse history of CO₂ Emissions: <https://www.youtube.com/watch?v=SAhZ1fA1AJs>

Activity 4.3: Tiny World Modeling (50 min)

- 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

Activity 4.4: Global Computer Model (50 min)

- Global Computer Model (currently at http://carbontime.bsccs.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

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

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

Activity 5.1: Extreme Makeover: Lifestyle Edition (45 min)

- 5.1 Extreme Makeover: Lifestyle Edition PPT
- 5.1 Lifestyle Cards (1-2 sets per class)
- 5.1 Extreme Makeover: Lifestyle Edition Worksheet (1 per student)
- 5.1 Secrets Revealed! Worksheet (1 per student)

Activity 5.2: Carbon Emissions Jigsaw (60 min)

- [5.2 Carbon Emissions Jigsaw PPT](#)
- [5.2 Group A Electricity Handout](#) (1 per student in Group A)
- [5.2 Group A Electricity Worksheet](#) (1 per student in Group A)
- [5.2 Group B Transportation Handout](#) (1 per student in Group B)
- [5.2 Group B Transportation Worksheet](#) (1 per student in Group B)
- [5.2 Group C Buildings Handout](#) (1 per student in Group C)
- [5.2 Group C Buildings Worksheet](#) (1 per student in Group C)
- [5.2 Group D Food Handout](#) (1 per student in Group D)
- [5.2 Group D Food Worksheet](#) (1 per student in Group D)
- [Jigsaw Cards](#) (1 per class)

Activity 5.3: Energy Scenarios (30 min)

- [5.3 Energy Scenarios PPT](#)
- [5.3 Energy Scenarios Cards](#) (1 per class)
- [5.3 Energy Scenarios Placemat](#) (1 per pair of students)

Activity 5.4: Strategies for Lowering Carbon Emissions (45 min)

- [5.4 Strategies for Lowering Carbon Emissions PPT](#)
- [5.4 Strategy Cards](#)

Activity 6.1: Using Models to Predict Future Conditions (50 min)

- [6.1 Using Models to Predict Future Conditions Worksheet](#) (1 per student)
- [6.1 Grading Using Models to Predict Future Conditions Worksheet](#)

Activity 6.2: How Our Decisions Affect Earth's Future (30 min)

- [6.2 How Our Decisions Affect the Earth's Future PPT](#)

Activity 6.3: Human Energy Systems Unit Posttest (20 min)

- [6.3 Human Energy Systems Unit Posttest](#)
- [6.3 Grading the Human Energy Systems Unit Posttest](#)