Human Energy Systems Unit 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:

- Investigate patterns of change in Earth systems (global temperatures, global sea levels, Arctic sea ice, atmospheric CO_2) 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 CO_2 pool;
- Explain how human actions affect CO_2 fluxes; and
- Predict effects of changes in human actions on the atmospheric CO_2 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 ecosystems. 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 ecosystems 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

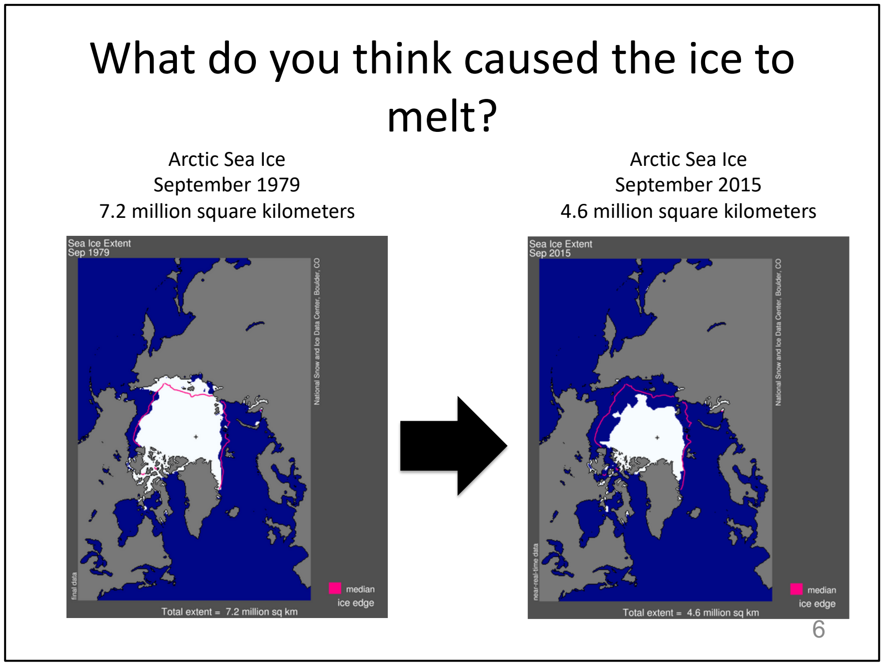
Human Energy Systems is the culminating unit in the *Carbon TIME* sequence, focusing on global-scale phenomena: climate change and global carbon cycling. We recommend that teachers complete the *Systems & Scale, Plants,* and *Ecosystems* units before the *Human Energy Systems* unit if possible. The foundational 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 CO_2?). In each phase students practice the roles of questioner, investigator, and explainer.

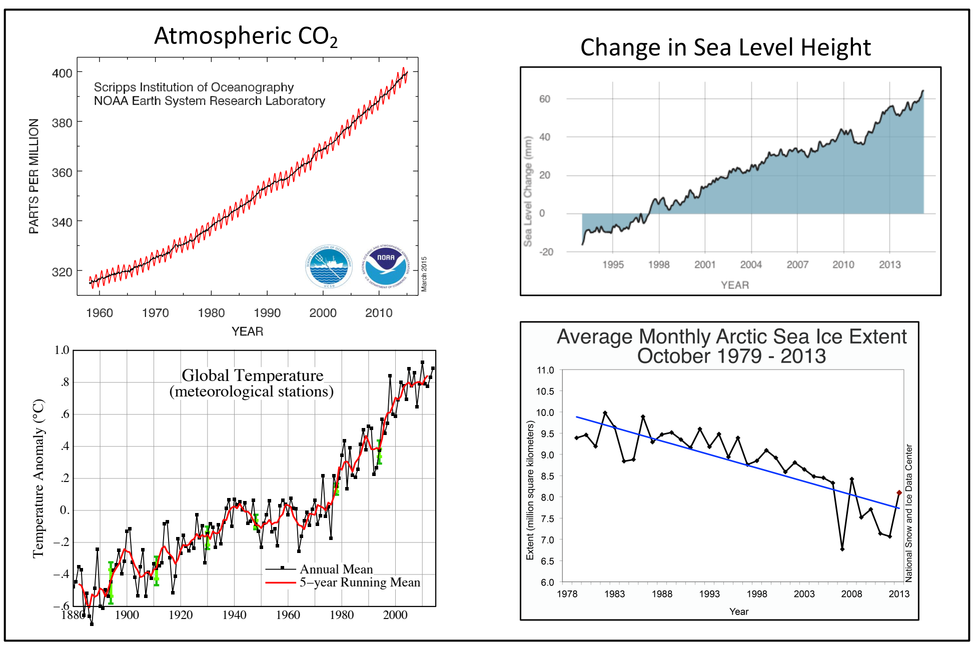
Phase 1: What is happening to the planet? (climate change)

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 CO_2 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.

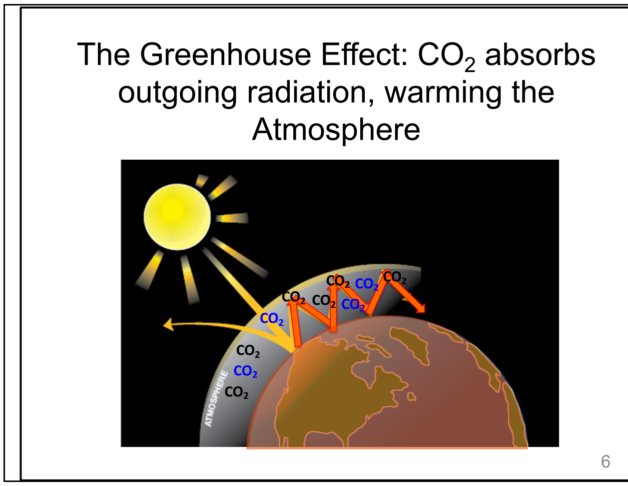


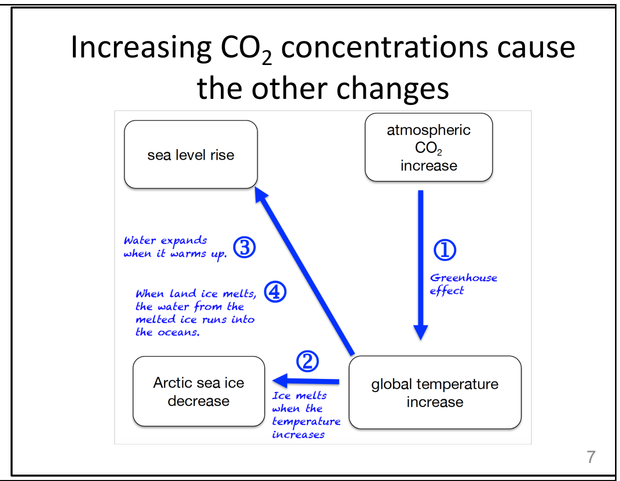
Lesson 2: Students investigate multiple representations of data about three other phenomena, comparing the representations to look for patterns in the data. They end the lesson with four clear long-term trends:



- The extent of Arctic sea ice is decreasing
- Sea levels are rising
- Global average temperatures are rising
- Global concentrations of CO_2 are rising

Lesson 3: Students learn about the Greenhouse effect and use it to explain the connections among the long-term trends: Increasing CO_2 levels are causing increases in global temperatures; the increasing temperatures are causing sea level to rise and ice to melt. Thus, atmospheric CO_2 is the driver—the factor that causes change in the other variables.





Phase 2: What causes changes in CO_2? (global carbon cycling)

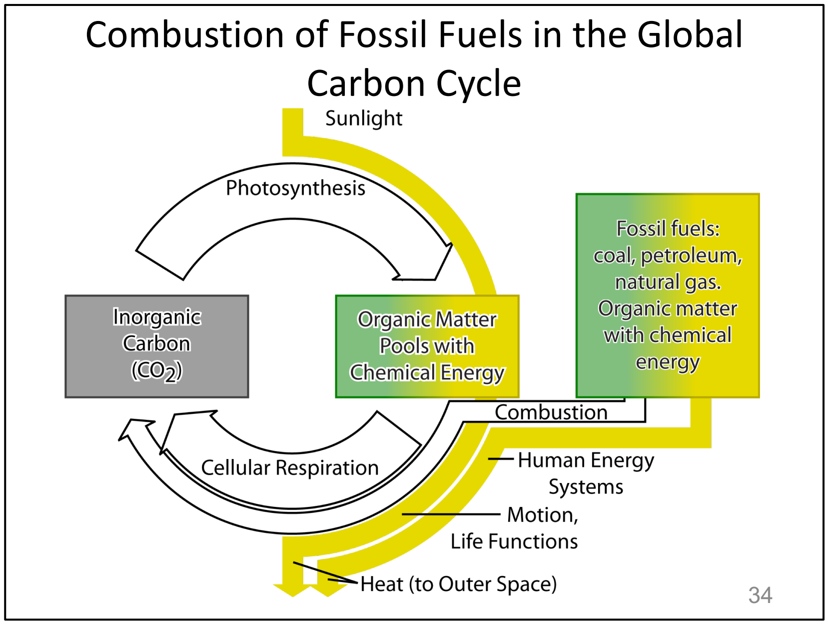
In the second half of the unit students investigate and explain "what drives the driver"—what is causing changes in atmospheric CO_2 levels.

Lesson 4: Students begin by sharing questions and hypotheses and make predictions about how reducing fossil fuel use will affect atmospheric CO_2 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)

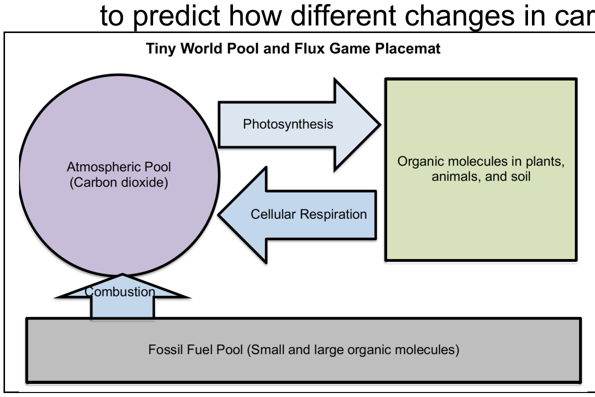
In particular, students should learn to answer the Four Questions in three important contexts:

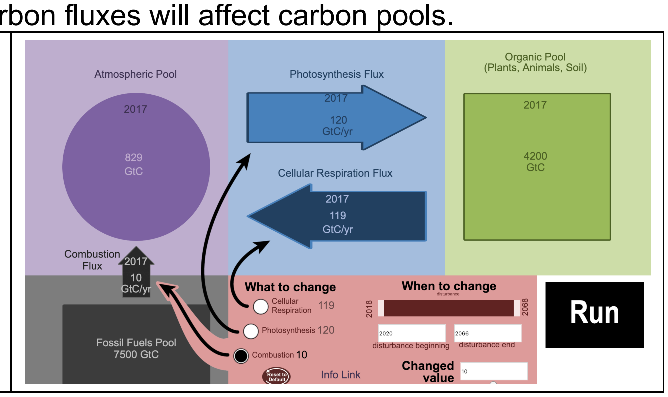


1. At the macroscopic scale, they relate our economic activities and lifestyle choices to carbon-transforming processes, especially combustion of fossil fuels. Students should understand both activities that directly use fossil fuels (such as driving a car) and activities that indirectly use fossil fuels (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.

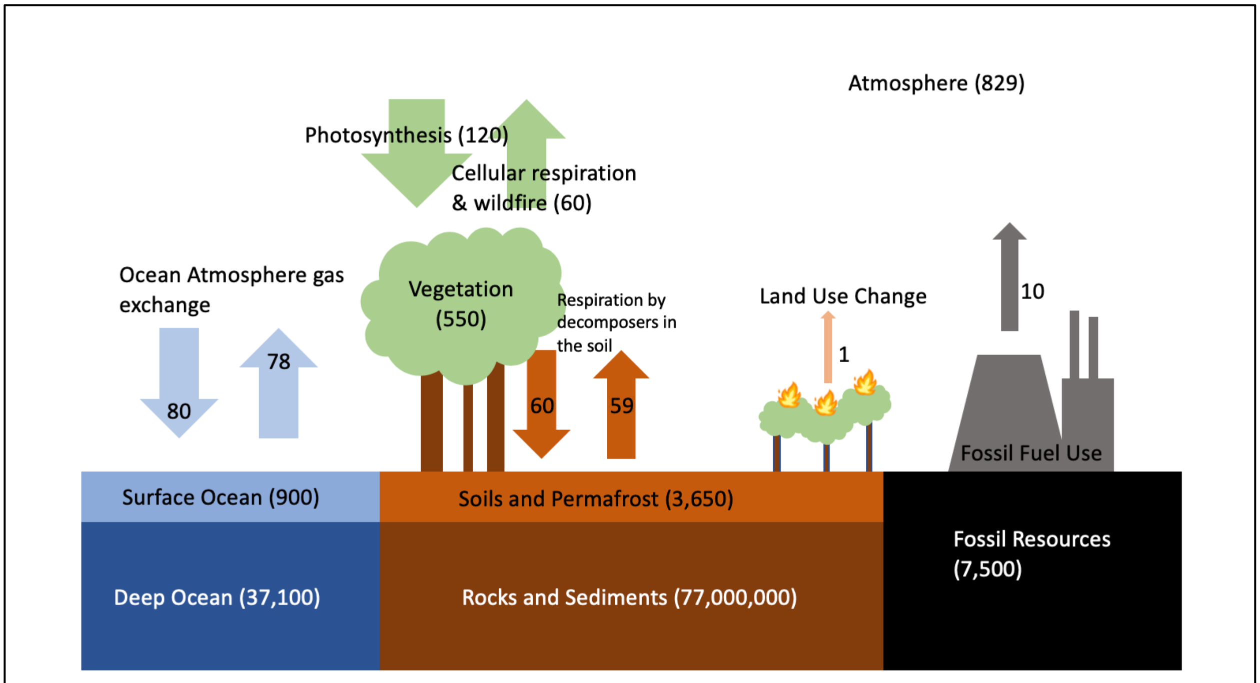
Students use three different kinds of pool-and-flux models to explain both the annual cycle and the long-term trend in CO_2 concentrations:

- 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.



All values in GtC. Carbon pool numbers have (parentheses), and flux numbers are with arrows. Data taken from USDA and U.S. Forest Service

Lesson 5: Students learn from Lesson 4 that combustion of fossil fuels is the unbalanced flux that drives the continuing increase in atmospheric CO_2 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 CO_2 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.