Ecosystems Unit Overview

The *Ecosystems* Unit starts by asking students to express their ideas about the driving question about an anchoring phenomenon, "How many foxes can live in a meadow?"

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 ecosystems 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

As students learn to answer the driving question by explaining how ecosystems transform matter and energy, they play three different roles that encompass all of the *Next Generation Science Standards* **science and engineering practices**. (For more details on science and engineering practices, see the Unit Goals.)

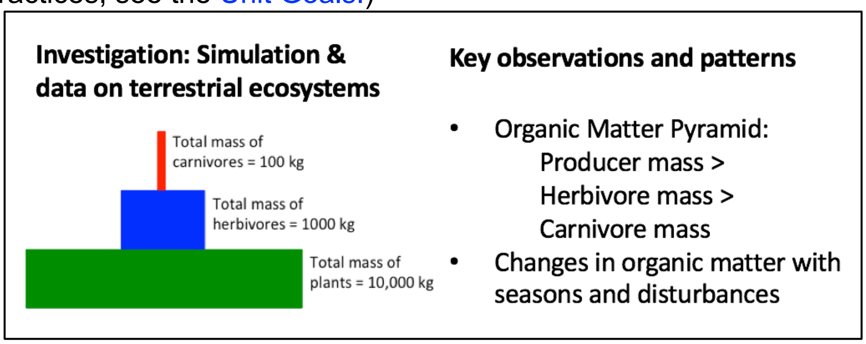


Figure 1: Results of investigation of a meadow simulation

- Questioners: Students explore the driving question, clarify, and generate more detailed questions
- Investigators: Students conduct investigations using a simulation of a meadow ecosystem and develop evidence-based arguments about key observations and patterns
- Explainers: Students construct model-based explanations of how carbon cycles and energy flows in different types of terrestrial ecosystems.

The roles that students play are embedded in the *Carbon TIME* Instructional Model and Discourse Routine. The Discourse Routine guides how classroom discourse aimed first at divergent thinking and then at convergent thinking should be sequenced through the unit.

Good Explanations Answer the Large-scale Four Questions

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 ecosystems. 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 ecosystems, 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.
    - Ecosystem scale (tracing fluxes of carbon and energy through different matter pools in ecosystems)
    - 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)

The Carbon Pools Question: Where are the carbon pools in our environment?

Students to answer the Large-scale Four Questions for different ecosystems, beginning with the anchoring phenomenon of a meadow ecosystem as an example. They identify five carbon pools in each ecosystem.

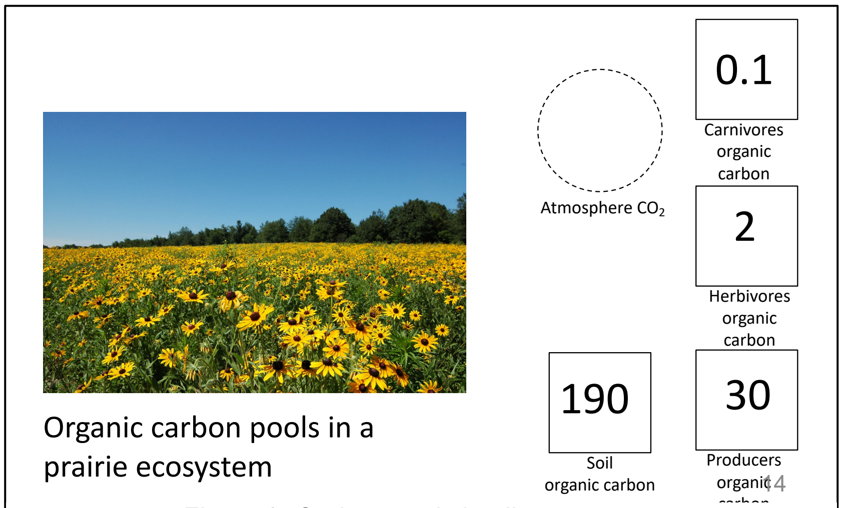


Figure 2: Carbon pools in all ecosystems

- Atmospheric carbon dioxide: the only inorganic carbon pool.
- Producers: the organic carbon in plants and other photosynthetic organisms
- Herbivores: animals that eat plants
- Carnivores: animals that eat animals
- Soil organic carbon: detritus such a fallen leaves, dead plants and animals, and decomposers that use organic materials in the soil as a food source

The Carbon Cycling and Energy Flow Questions: Explaining How Matter and Energy Move and Change in Ecosystems

Students begin the unit by investigating relationships among the sizes of carbon pools and find the pattern of relationships shown in Figures 1 and 2 above: The producer organic matter pool is much bigger than the herbivore pool, and the herbivore pool is much bigger than the carnivore pool.

Students learn to explain these patterns using *carbon fluxes* that move materials from one carbon pool to another. Carbon fluxes depend on processes, such as photosynthesis and cellular respiration, that take place inside individual organisms. They involve physical movement and chemical changes in matter, driven by changes in energy. Students study the carbon pools and fluxes shown in Figure 3 below.

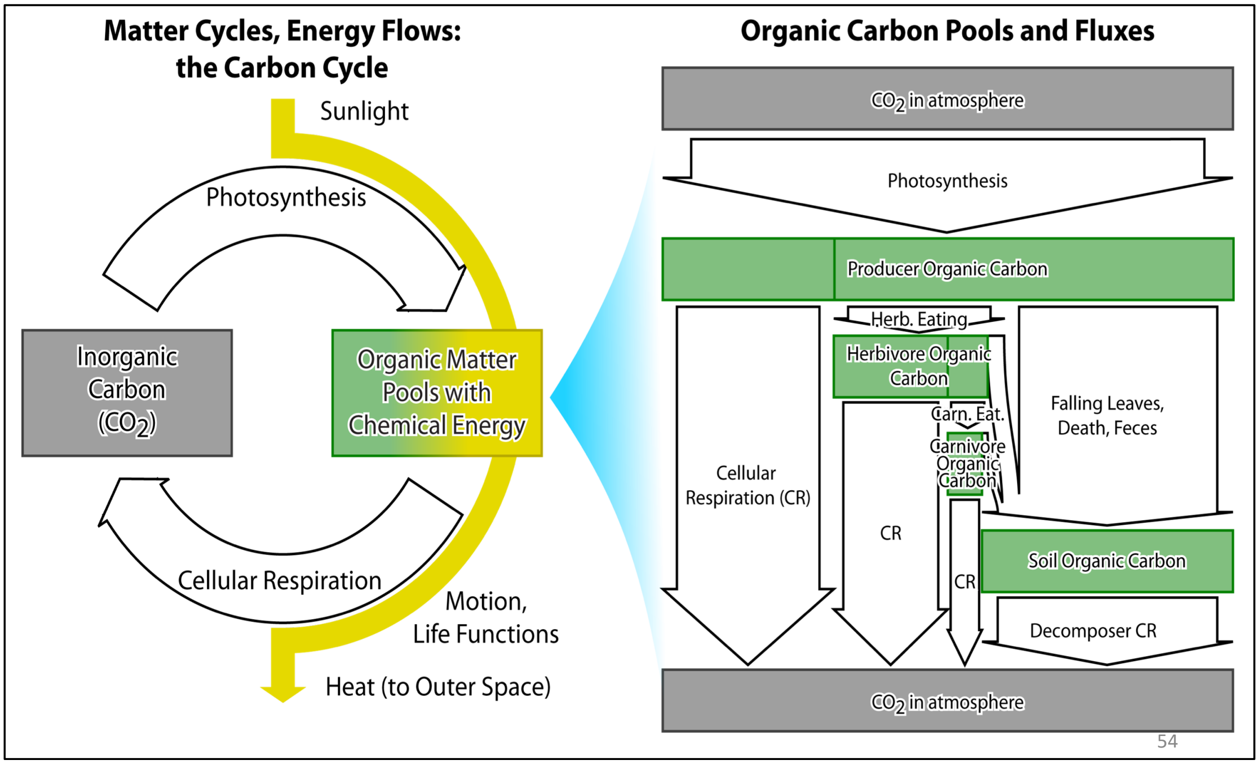


Figure 3: Carbon cycling and energy flow in terrestrial ecosystems

The big picture: The left side of Figure 3 shows the general pattern of carbon cycling and energy flow in all ecosystems:

- There are two big carbon pools: Carbon dioxide in the air and organic matter in living and dead organisms.
- There are two big carbon fluxes: Photosynthesis changes carbon dioxide and water into organic carbon and oxygen; cellular respiration completes the cycle, turning organic carbon and oxygen back into carbon dioxide and water.
- Energy flows through the ecosystem: Sunlight is converted into chemical energy in organic matter, which is released through cellular respiration, ultimately becoming heat that the Earth radiates into outer space.

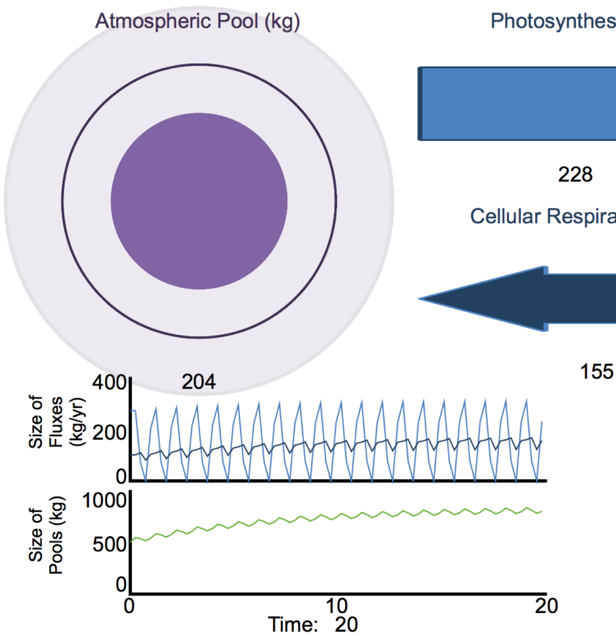
Details of organic matter pools and fluxes: The right side of Figure 3 shows details of pools and fluxes inside the large organic matter pool. Food chains and food webs are a part of this story, but not the whole story. Plants use the organic materials that they create with photosynthesis for growth and energy (cellular respiration). The materials in plant bodies move to other pools when the plants are eaten or when dead plant materials become detritus in the soil. Ultimately organic materials are oxidized to carbon dioxide and water through cellular respiration in plants, animals, and decomposers.[1]

The Stability and Change Question: How do carbon fluxes change the size of carbon pools?

(Note: The Stability and Change Question is addressed mostly in Lesson 4, which is optional for middle school students since modeling of processes that change ecosystems is addressed primarily in *NGSS* High School Performance Expectations—see the Unit Goals tab.)

[1] Some soil carbon can remain in the soil for a very long time, ultimately becoming fossil fuels. These processes are discussed in the *Human Energy Systems* Unit.

Ecosystems are constantly changing. Students learn to analyze how changes in ecosystems affect carbon pools and fluxes using quantitative online models (illustrated in Figure 4 below) and by studying cases of different ecosystems.



	t=0	t=20	t=E
Atmospheric (kg)	500	204	204
Organic (kg)	500	795	795
Photosynthesis (kg/yr)	270	228	228
Cellular Respiration (kg/yr)	100	155	155

Figure 4: Computer simulation of pools and fluxes in an ecosystem with changing seasons

Students analyze how carbon cycling and energy flow are affected by three kinds of changes in ecosystems:

- *Seasonal changes* affect the photosynthesis flux in particular, changing the balance of fluxes and the sizes of the organic matter and CO_2 pools.
- *Human management* in ecosystems such as farms and ranches: Humans alter the environment so that ecosystems produce goods and services that we need.
- *Disturbances* such as fires and droughts change carbon fluxes and carbon pools.

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 is 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.