Systems and Scale Unit Overview

The Driving Question and Research Base

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The *Systems and Scale Unit* starts by asking students to express their ideas and generate questions about the driving question about an anchoring phenomenon: *What happens when ethanol burns*?

Carbon is the key! In the unit, students learn to tell the story of how matter and energy are transformed as they move through systems. A particularly powerful strategy for explaining how 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 Matter Movement, Matter Change, and Energy Change 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 Systems and Scale 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 flames 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.)

- Questioners: Students explore the driving question, clarify, and generate more detailed questions.
- Investigators: Students conduct two matter-tracing investigations of (a) soda water fizzing and (b) ethanol burning. They develop evidence-based arguments about key observations and patterns.
- Explainers: Students construct model-based explanations of how matter and energy are transformed when organic materials burn.

The roles that students play are also 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 Three Questions

Students figure out how to answer the driving question by tracing the carbon-containing molecules in fuels through a series of movements and chemical changes inside flames. At each stage in these processes they answer **Three Questions** about what is happening: the Matter *Movement Question, the Matter Change Question,* and the *Energy Change Question*.

Below, we use the anchoring phenomenon of a flame burning as an example of how students learn to answer the Three Questions for different organic materials burning.

Note that, in *Carbon TIME*, *NGSS* **crosscutting concepts** serve as the "rules of grammar" for producing a scientific performance. With respect to organic materials burning, high quality explanations should attend to the following rules that are implied by crosscutting concepts. Explanations should attend to…

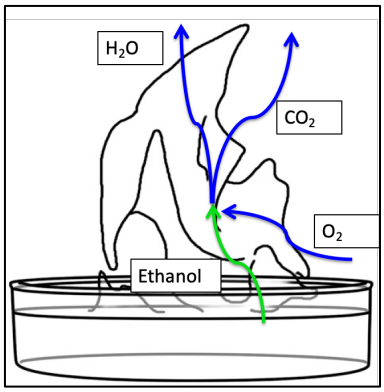
- *Scale* by explaining events and phenomena at the appropriate scale (see more in the structure and function bullets below).

- *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 such as a flame.
- *Structure and function* by linking structures and functions in explanations at each scale.
    - Macroscopic scale (tracing matter and energy through processes occurring in flames)
    - Atomic-molecular scale (tracing matter and energy through a chemical process—combustion—involving molecules with different structures and properties)

The Matter Movement Question: Tracing Molecules Through Flames

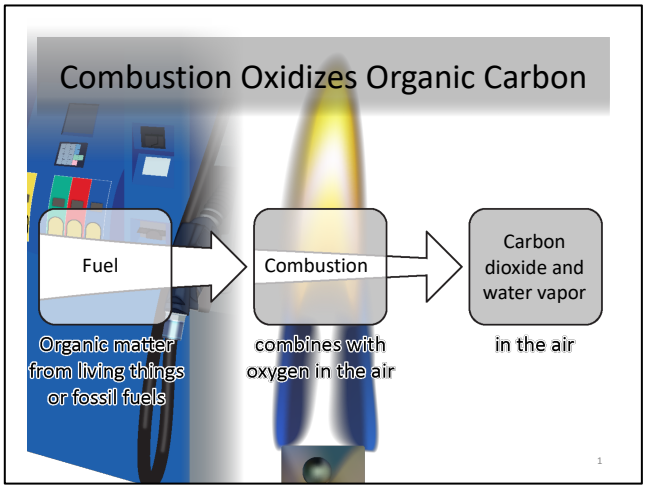
Students learn to tell the following story of how carbon-containing molecules move through the flame in burning ethanol.

- Ethanol (C_5H_2OH) evaporates and enters the flame, along with O_2 molecules from the air.
- Carbon dioxide and water vapor leave the flame.



The Matter Change and Energy Change Questions: Explaining How Combustion Changes Organic Materials

Matter movement is an essential part of the story, but not the whole story. To answer the driving question, students learn to explain chemical changes that occur inside flames:



- Matter Change: Students explain how the reactant molecules (ethanol and oxygen) break apart in the flame, and how their atoms then bond together to create new products (carbon dioxide molecules and water molecules).
- Energy Change: Students explain how the chemical energy in the reactant molecules, indicated by high-energy C-C and C-H bonds, is released when the products form lower-energy C=O and H-O bonds, releasing energy in the form of heat, light, and movement of air.

Students practice their explanations using multiple representations: (a) hand-on molecular models, (b) PowerPoint animations, (c) a chemical equation ($C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$), and (d) written paragraphs. They also practice on multiple examples of combustion, including combustion of methane, propane in a gas grill, octane in a gasoline engine, and wood.

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 to decide how much detail is appropriate for your students.