NGSS Tools Work: HSLS-1: Matter and Energy in Organisms and Ecosystems:
A Study of Matter and Energy in Systems

HS-LS1-5:

Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical reactions, and conceptual models

Assessment Boundary: Assessment does not include specific biochemical steps.

HS-LS1-6

Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form ~~amino acids and/or other~~ large carbon-based molecules.

Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.

Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.

HS-LS1-7

Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed, resulting in a net transfer of energy.

Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.

Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.

HS-LS2-3

Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.

Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.

HS-LS2-4

Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

Clarification Statement: Emphasis is on using a mathematical model of stored energy in biomass to describe the transfer of energy from one trophic level to another and that matter and energy are conserved as matter cycles and energy flows through ecosystems. Emphasis is on atoms and molecules such as carbon, oxygen, hydrogen, ~~and nitrogen~~ being conserved as they move through an ecosystem.

Assessment Boundary: Assessment is limited to proportional reasoning to describe the cycling of matter and flow of energy.

Performance Expectation 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~~.

Clarification Statement: Examples of models could include simulations and mathematical models.

Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.

HS.LS1.C: Organization for Matter and Energy Flow in Organisms

- The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. (HS-LS1-5)
- The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6)
- As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6), (HS-LS1- 7)
- As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken, andnew compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. (HS-LS1-7)

HS.LS2.B: Cycles of Matter and Energy Transfer in Ecosystems

- Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. (HS-LS2-3)
- Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. (HS-LS2-4)
- Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (HS-LS2-5)

HS.PS3.D: Energy in Chemical Processes

- The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. (Secondary to HS-LS2-5)

Developing and Using Models

Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-LS1-5), (HS-LS1-7)
- Develop a model based on evidence to illustrate the relationships between systems or components of a system. (HS-LS2-5)

Using Mathematics and Computational Thinking

Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena or design solutions to support claims. (HS-LS2-4)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS1-6), (HS-LS2-3)

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions— including energy, matter, and information flows—within and between systems at different scales. (HS-LS2-5)

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-LS1-5), (HS-LS1-6)
- Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems. (HS-LS1-7), (HS-LS2-4)
- Energy drives the cycling of matter within and between systems. (HS-LS2- 3)

A Study of Matter and Energy in Systems

Grade 9-10 General Biology

Length of unit: Approximately 3 weeks

Seven lesson unit

Unit Overarching Goal

In a closed system, matter is conserved and cycles within the system. Energy is conserved, but can enter and leave a closed system, thus flowing through the system. Through the processes of photosynthesis and cellular respiration, carbon molecules cycle between living and nonliving components. Through biological processes, carbon atoms are fixed into organic molecules that are rearranged into other organic molecules by organisms. Energy is transferred and transformed from solar to chemical energy during photosynthesis. Through the process of cellular respiration, chemical energy is transformed into kinetic and heat energy by living organisms. Because heat energy leaves the system, a continual input of solar energy is required to sustain the system. Using models, we can predict how changes in components affect the systems.

Unit Central Question

How do matter and energy move through a system as living things interact with each other and the environment?

Lesson	Main Learning Goal	Focus Question	Science Content Storyline
1	Within a system, there are identifiable boundaries, components, interactions, and inputs and outputs of matter and energy.	What are the characteristics of a system?	A system has boundaries, components, interactions, and inputs and outputs. In a closed system, you can identify the inputs and outputs as matter or energy. The terrarium represents a closed system with all identifiable characteristics of a system.
2	As a system, plants use inputs of water and carbon dioxide to create outputs of small carbon-based molecules (glucose) and oxygen through the process of photosynthesis. Matter is conserved throughout this process.	Where do the atoms that a plant uses in photosynthesis come from? Where do they go?	A plant, such as the one in the terrarium, is a system. Plants use a series of chemical reactions called photosynthesis to separate the atoms of water and carbon dioxide molecules and connect those atoms in different arrangements to make glucose and oxygen molecules. We can trace the atoms used in photosynthesis because matter is conserved in a system. Glucose molecules ($C_6H_{12}O_6$) are composed of carbon, hydrogen, and oxygen atoms which form the backbone of other large carbon molecules (such as starch). The oxygen produced as an output comes from the breakdown of the water molecules input into the system.
3	The process of photosynthesis is a series of chemical reactions that both require and release energy. However, a net input of light energy is required. The amount of light energy can affect the rate of photosynthesis.	What is the role of energy in creating the outputs of photosynthesis?	An input of energy is required to separate the atoms of the reactant molecules of carbon dioxide and water. Energy is released as atoms connect to form products of glucose and oxygen. Because the energy required to separate the atoms of the reactant molecules (carbon dioxide and water) is greater than the energy released in the formation of product molecules (small carbon-based molecules), the reactions of photosynthesis require a net input of energy. This input of energy comes from light energy.

Lesson	Main Learning Goal	Focus Question	Science Content Storyline
4	The process of cellular respiration is a series of chemical reactions that both require and release energy. These reactions yield a net release of energy that can be used to form large carbon-based molecules that can be used for growth and reproduction as well as fuel in chemical reactions.	How do plants use the outputs of photosynthesis?	The process of cellular respiration is a series of chemical reactions that both require and release energy. Plants use cellular respiration reactions to separate the atoms of glucose and oxygen and connect those atoms in different arrangements to form larger carbon-based molecules such as starch. An input of energy is required to separate the atoms of the reactant molecules (glucose and oxygen), and energy is released as atoms connect to form new product molecules (carbon dioxide and water). Because the energy required to separate the atoms of the reactant molecules is less than the energy released in the formation of product molecules, the reactions of cellular respiration result in a net output of energy. Some of this energy is used in other chemical reactions, some energy leaves the plant as heat. Plants use some large carbon-based molecules to grow by organizing the molecules into roots, stems, leaves, and reproductive structures. They use other large carbon-based molecules and oxygen molecules as fuel in chemical reactions. The products of these chemical reactions are simple molecules of carbon dioxide and water which are returned to the environment.
5	Other organisms, including animals, perform cellular respiration to form large molecules through both aerobic and anaerobic processes which can be used for growth, reproduction, and as fuel for chemical reactions.	How do other organisms use the outputs of photosynthesis?	Energy transfers and matter cycles between organisms. Some organisms use aerobic cellular respiration producing large amounts of energy for other systems. Some organisms (bacteria) produce energy through an anaerobic process, providing smaller energy outputs for other systems inputs. Aerobic respiration requires the inputs of oxygen and glucose. In anaerobic respiration, oxygen is not required as an input. As a result of respiration, outputs of CO2 and H2O are produced. Some of the glucose molecules are not used in respiration but are used to build large carbon-based molecules (such as proteins) to grow.
6	The Earth's biosphere is a system in which matter and energy interact.	How do matter and energy move through the biosphere as living things interact with each other and the environment?	Matter, including carbon and water, cycles through the biosphere. Energy flows through the biosphere as light energy is transformed into chemical energy, which is transferred between organisms and leaves as thermal energy. Matter and energy are conserved as they move between organisms and the environment, meaning that the number of atoms and the amount of energy remains the same.
7	Using models we can predict how changes in components affect the systems.	How does a change in one component of the biosphere system affect the other components of the system?	Changes in a system can be described and predicted in terms of inputs and outputs to the system. As humans release stored carbon by burning fossil fuels, carbon dioxide increases in the atmosphere. Increases in atmospheric CO2 change the rate and amount of the outputs of photosynthesis.