# Living Earth Unit 2

# History of Earth's Atmosphere: Photosynthesis and Respiration

### Background for Teachers and Instructional Suggestions

At the middle grade level, students **explained** the role photosynthesis plays in cycling of matter by the production of sugars (food) using light energy and carbon dioxide (***MS-LS1-6***), and **developed a model** of how food molecules can be rearranged to extract usable energy (*MS-LS1-7*). Students are already familiar with ***cycles of matter*** *within* a ***system*** from the middle school investigation of the water cycle (*5-LS2-1*, *MS-ESS2-4*). In this instructional segment, students explore the cycling of matter *between* the biosphere and the rest of Earth's systems***.***

Energy is needed by all living organisms in order for there to be life. Students will construct a model showing how an autotrophic organism (producer, mostly plants and algae) transforms sunlight (or light energy) into useable forms of chemical energy for living organisms (*HS-LS1-5*). The details of different biochemical processes are not assessed by the *CA NGSS*. The main emphasis is on tracing the overall flow of matter and energy within and between organisms. Photosynthesis involves two interdependent cellular processes, the first is the capturing of sunlight/light energy by chloroplasts and the second is using that energy to fix atmospheric carbon dioxide into a glucose molecule. This can then be stored by the producer as many glucose molecules attached together in the form of starch (where it takes up less room and therefore is easier to store) or it can be used directly as glucose (see below). Heterotrophs (consumers or animals) ingest producers as food that will then be used for energy and building blocks for growth. Consumers often store energy in stacked glucose molecules in the form of glycogen (in higher animals this is stored in liver and muscle tissues).

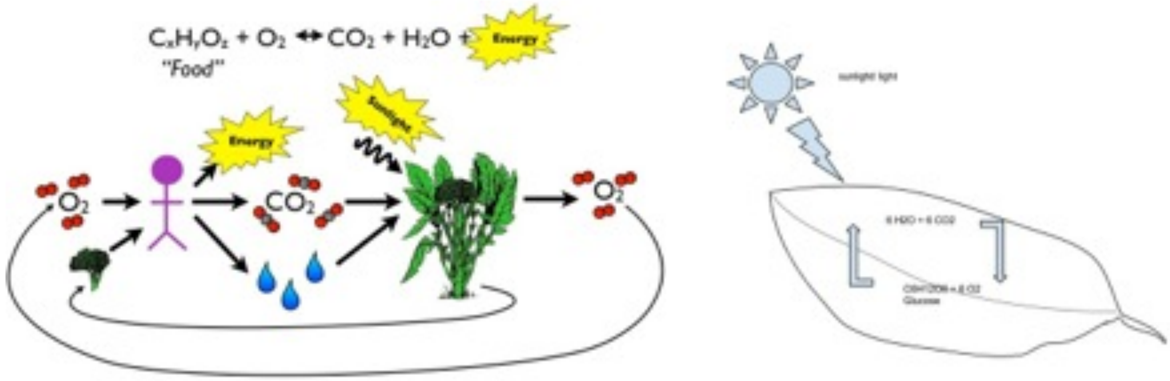


**Figure 2.** Examples of models showing how photosynthesis and respiration are mirrors of one another, involving the same basic ingredients. Matter cycles within the Earth system between the two processes, but energy must constantly flow in as sunlight to replace the energy put to work by organisms to grow and survive.

Photosynthesis converts sunlight into the chemical potential energy between atoms in glucose. In order to grow and survive, both plants and animals must use cellular respiration to take this stored energy and put it to work. Cellular respiration is the process by which organic molecules are broken down to release energy and molecules of adenosine triphosphate (ATP) are formed. Breaking the glucose down, rearranging, and reassembling it requires additional oxygen input and releases carbon dioxide. The ATP formed in cellular respiration has high levels of potential energy that allow cells to do work and therefore, if there is no ATP then there is no life. The energy from ATP is released when it is converted back into adenine diphosphate (ADP).

The interrelatedness of photosynthesis and cellular respiration is important to keep ATP available and at a relatively constant level in all cells. The products of photosynthesis are used as the reactants for cellular respiration and vice versa. However, as stated in the second Law of Thermodynamics as energy is transferred, there will be less energy available in a useable form for the organism. This means that the overall processes are always losing energy and there needs to be a constant influx of energy into the system which comes from the sun as light energy. Some organisms that do not live in oxygen rich environments (like organisms that live near thermal vents deep in the ocean) use a different energy pathway.

Taking the physical components of glucose (carbon, oxygen and hydrogen, the matter) students can model how to build a glucose model and how to split it up (with an emphasis on the components needed to build the glucose and the components left after the breakdown of the glucose) (*HS-LS1-5*, *HS-LS1-7*). They should start with the atoms of carbon, hydrogen and oxygen and make the simple molecules of $CO_2$, $H_2O$ and $O_2$ and then trace the movement of these. For example, the carbon dioxides and water will be united through photosynthesis and then released again in cellular respiration showing the importance of carbon cycling in this process (which directly links to and should be connected to carbon cycling learning in earth science). Carbon is structurally important to building all biological molecules including the glucose molecule. At this time students can be guided though the importance of why carbon is an atom found in all living molecules noting the size of the atom, the ability to covalently bond to four other atoms, placement of their electrons and the ability to form single and double bonds with other atoms. ***Energy flows*** into the ***system*** when glucose is formed and out of the ***system*** when it is processed, providing evidence in support of the First Law of Thermodynamics (*HS-PS3-1*).

When did the cycling of ***energy and matter*** start on Earth and how is cycling maintained? When asked what the Earth might have looked like 4.6 billion years ago when it first formed, students' image might be informed by prior knowledge that may include non-scientific sources and may not be consistent with the scientific understanding that Earth was lifeless. Teachers may need to explicitly discuss existing ideas and their sources before beginning instruction. When Earth first formed, its interior was still very hot and its interior rapidly convected (ties to *HS-ESS2-3*). Hot magma rising up is part of convection, so rapid convection caused volcanic activity in Earth's early history. When these volcanoes erupted, they released large amounts of gas that built up our early atmosphere with $CO_2$. Around 3.4 billion years ago, organisms evolved that could perform photosynthesis, which disassembles $CO_2$ (as described above). This marked the beginning of life's interaction with the global carbon cycle, an example of Earth's interacting ***system*** of systems (biosphere interacts with atmosphere). In CA NGSS, students must use evidence like the graph in Figure 3 and their model of photosynthesis (*HS-LS1-5*) to construct an **argument** that life has been an important influence on other components of the Earth system (*HS-ESS2-7*).

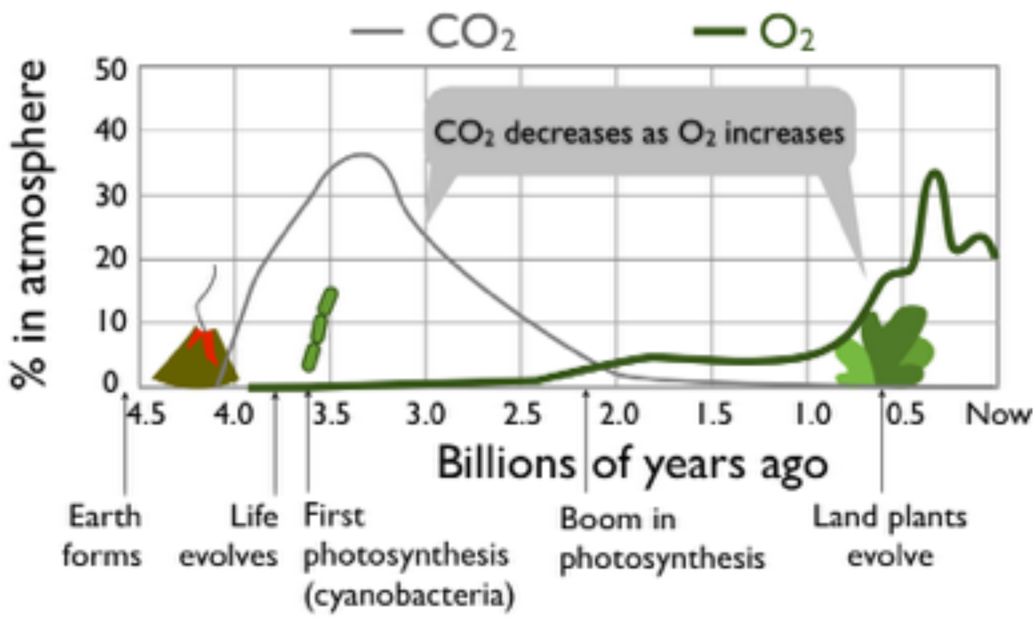


**Figure 3.** Concentration of $CO_2$ and $O_2$ in Earth's atmosphere over its history. Dramatic changes happened as plants used $CO_2$ to grow their biomass and released $O_2$ during photosynthesis. Image credit: (CC-BY-NC-SA) by M. d'Alessio, based on data from Holland 2006**.**

Dissecting the carbon cycle will help students see the connections to Earth ***systems*** and how that can maintain life. The exchange of carbon between the atmosphere and the biosphere is just one of many important interactions between Earth's systems that involve the movement of carbon. In fact, one of the few additions that California made in adopting the *CA NGSS* was to add this sentence to the Clarification Statement for Performance Expectation *HS-ESS2-6*: "The carbon cycle is a property of the Earth system that arises from interactions among the hydrosphere, atmosphere, geosphere, and biosphere." Scientists track the movement of carbon atoms through the carbon cycle much like they track the movement of water molecules through the water cycle. In both cases, scientists think about the cycle of matter within a closed system because at this point in Earth's history, very little water or carbon leaves the planet or arrives from space. We simply need to track the movement of the matter that is already here. A biological model of the carbon cycle is shown in instructional segment 1.

In the *CA NGSS*, students must develop a quantitative **model** of the carbon cycle (*HS-ESS2-6*), which needs to include knowledge of:

1. Places where carbon accumulates within the Earth system (called 'reservoirs', reminiscent of the storage of water in the water cycle);
2. Processes by which carbon can be exchanged within and between reservoirs (called 'flows');
3. The relative importance of these processes and reservoirs, based on the amount of carbon they hold or transfer.

Various representations exist for the carbon cycle, including simple pictures like Figure 1. Interactive animations[1], hands-on experiments[2], and kinesthetic activities build on the static illustrations to help students develop conceptual models of the reservoirs and processes by which carbon is exchanged between these reservoirs. For example, students can conduct a simple **investigation** that **models** the flow of $CO_2$ by adding pH indicator in water (See instructional segment 1 of the chemistry course). As a plant grows, a candle burns, or a person exhales through a straw into the water, the pH changes as $CO_2$ interacts with the water to form carbonic acid. This same chemical reaction happens at the global scale with interactions between the atmosphere and the hydrosphere (PS1.B; instructional segment 6 of the chemistry course), making Earth's oceans one of the biggest reservoirs of carbon on the planet (see Table 1 for the relative sizes of different reservoirs). Students should be able to explain how the concentration of $CO_2$ in the atmosphere affects the rate of the chemical reaction in *HS-PS1-5* and the final concentration of acid in the ocean is an example of a system in equilibrium as is explored in *HS-PS1-6*. Because the system is near equilibrium, massive amounts of carbon (~80 Gt) are absorbed into the ocean while massive amounts are also released back to the atmosphere. These opposite flows are similar in magnitude but do not

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[1] http://d3tt741pwxqwm0.cloudfront.net/WGBH/pcep14/pcep14_int_co2cycle/index.html

[2] http://www.omsi.edu/sites/all/FTP/files/chemistry/U4BurningIssues_OpGuide.pdf

balance out – the ocean is absorbing about 2.5 Gt/yr of carbon from the atmosphere more than it releases back, causing the ocean to become more acidic. An acidic ocean can cause major damage to plankton (that form the base of the ocean food chain, LS2.A, LS2.B) and coral reefs (which host a large portion of the ocean's biodiversity), both of which have broad ramifications for sea life (LS3.C) (human impacts are addressed in instructional segment 6). Scientists use complex computer models to calculate the expected changes in ocean chemistry based on different human activities, and CA NGSS pushes students to use simple computer representations of **models** like these to illustrate the relationships between different Earth ***systems*** and how those systems are being modified due to human activities (*HS-ESS3-6*).

**Table 1.** Carbon reservoirs and atmospheric flows

| CARBON RESERVOIRS AND ATMOSPHERE FLOWS | | | |
|---|---|---|---|
| RESERVOIR | FORM OF CARBON | AMOUNT IN RESERVOIR | FLOW RATE WITH ATMOSPHERE |
| Atmosphere | Mainly carbon dioxide (gas) | 840 Gt | Greenhouse gases are increasing due to human activities. |
| Biomass (*biosphere*) | Sugar, protein, etc. (solid, liquid) | 2,500 Gt (mostly in plants and soil) | About 120 Gt per year into and out of air. Currently absorbing about 2.5 Gt per year |
| Ocean (hydrosphere) | Mostly dissolved bicarbonate salts | 41,000 Gt | About 80 Gt per year into and out of air. Currently absorbing about 2.5 Gt per year |
| Sedimentary rocks (*geosphere*) | Carbonate minerals (solid) | 60,000,000 Gt | Negligible annually but important over very long time scales. |

| | | | |
|---|---|---|---|
| Fossil Fuels (*geosphere/* anthrosphere) | Methane (gas)<br>Petroleum (liquid)<br>Coal (solid) | 10,000 Gt | About 9 Gt/year into atmosphere, mostly from burning as fuels for energy. |
| Units are Gigatons (Gt) of carbon. 1 Gt = 1 billion tons | | | |

Table 1 also reveals that the single largest reservoir of carbon is not in the air or water, but in rocks. How does it get there? When students learn about the chemical composition of life (LS1.C), they are able to explain why carbon is so important for so many of life's ***systems*** (*HS-LS1-6*) (mentioned above in why carbon is a good atom for living organisms). Living organisms are therefore a large reservoir of carbon. When those organisms die, the carbon they have stored in their bodies can accumulate in layers that get buried over geologic time (will be discussed more in instructional segment 3). Heat and pressure caused by burial speed up chemical reactions that slowly reorganize the carbon and other elements into new, easily combustible molecules that we call fossil fuels, including oil (petroleum) and natural gas (including methane). To ensure that students see the connection between past life and oil formation, students could draw the stages of oil formation to summarize an article presented written or orally[3]. Extracting oil and gas from deep within the Earth and burning it allows us to harness energy that was collected by ancient plants and animals millions of years ago but has been stored as chemical potential energy in materials trapped underground for millions of years. These materials are incredibly valuable for generating electricity, fueling our vehicles, and generally enabling modern society to thrive. Unfortunately, fossil fuels form very slowly and only under specific conditions and therefore considered 'non-renewable' because we consume them faster than they form. Access to fossil fuels occurs in specific places on Earth and California has large deposits.

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[3] http://www.switchenergyproject.com/education/CurriculaPDFs/SwitchCurricula-Secondary-NaturalGas/SwitchCurricula-Secondary-ExploringOilAndGas.pdf p. 13 & 57