IS1

## Earth and Space Sciences Instructional Segment 1: Oil and Gas

Without energy, California's transportation and commerce would come to a screeching halt. More than half of our electricity and almost all of our transportation is currently provided by fossil fuels. California holds about 10 percent of all the proven oil reserves in the United States and is currently the third largest oil producing state in the country. This instructional segment explores where those fuels came from and the effects that extracting and burning them have on our global climate.

### EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 1: OIL AND GAS

**Guiding Questions**

- Where do oil and gas come from?
- How are gas and oil deposits related to carbon cycling and Earth systems?
- What is the impact of driving cars and using other fossil fuels on the Earth systems?

**Performance Expectations**

Students who demonstrate understanding can do the following:

**HS-ESS2-1.** Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features. [Clarification Statement: Emphasis is on how the appearance of land features (such as mountains, valleys, and plateaus) and sea-floor features (such as trenches, ridges, and seamounts) are a result of both constructive forces (such as volcanism, tectonic uplift, and orogeny) and destructive mechanisms (such as weathering, mass wasting, and coastal erosion).] [*Assessment Boundary: Assessment does not include memorization of the details of the formation of specific geographic features of Earth's surface.*] (Introduced here, but revisited from in IS3 and again in IS4)

**HS-ESS2-6.** Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere. [Clarification Statement: The carbon cycle is a property of the Earth system that arises from interactions among the hydrosphere, atmosphere, geosphere, and biosphere. Emphasis is on modeling biogeochemical cycles that include the cycling of carbon through the ocean, atmosphere, soil, and biosphere (including humans), providing the foundation for living organisms.]

## EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 1: OIL AND GAS

**HS-ESS2-7.** Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth. [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples include: how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [*Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.*]

The bundle of performance expectations above focuses on the following elements from the NRC document *A Framework for K–12 Science Education*:

| Highlighted Science and Engineering Practices | Highlighted Disciplinary Core Ideas | Highlighted Crosscutting Concepts |
|---|---|---|
| [SEP-2] Developing and Using Models<br>[SEP-7] Engaging in Argument from Evidence | ESS2.A: Earth Materials and Systems<br>ESS2.B: Plate Tectonics and Large-Scale System Interactions<br>ESS2.D: Weather and Climate<br>ESS2.E: Biogeology<br>ESS3.A: Natural Resources | [CCC-5] Energy and Matter: Flows, Cycles, and Conservation<br>[CCC-7] Stability and Change |

**Highlighted California Environmental Principles and Concepts:**

**Principle III** Natural systems proceed through cycles that humans depend upon, benefit from and can alter.

**Principle IV** The exchange of matter between natural systems and human societies affects the long-term functioning of both.

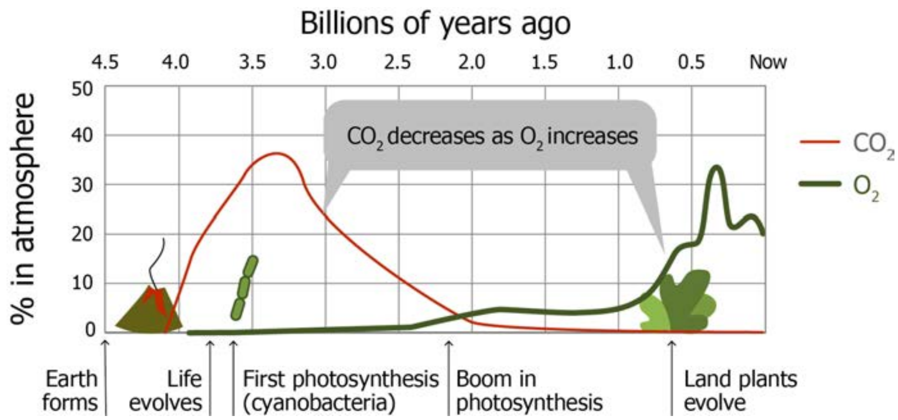
**CA CCSS Math Connections:** N-Q.1–3; MP.2, MP.4

**CA CCSS for ELA/Literacy Connections:** WHST.9–12.1a–e

**CA ELD Connections:** ELD.PI.11–12.1, 5, 6a–b, 9, 10, 11a

Understanding the importance of fossil fuels begins with an understanding of the interactions among life, the atmosphere, and rocks over geologic time (ESS2.A, ESS2.E). When asked what the Earth might have looked like when it first formed 4.6 billion years ago, students' images might be informed by prior knowledge that may include nonscientific 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, a process which disassembles $CO_2$. This marked the beginning of life's interaction with the global carbon cycle, an example of Earth's interacting **system [CCC-4]** of systems (biosphere interacts with atmosphere). In the CA NGSS, students must use evidence like the graph in figure 8.45 and their model of photosynthesis (HS-LS1-5) to construct an **argument [SEP-7]** that life has been an important influence on other components of the Earth system (HS-ESS2-7). Early on, ocean water and chemical reactions with rock material absorbed much of the oxygen that plants produced. By examining records from rock layers, students can reconstruct aspects of Earth's early history (HS-ESS1-6). They can see evidence of biosphere-geosphere interactions in deep red rock layers that accumulated at the bottom of the ancient ocean called "banded iron" (because they are rich in red iron oxides). The oldest banded iron formations provide evidence of when plants first evolved, and thick deposits of banded iron about 2.4–1.9 billion years ago reveal another major **change [CCC-7]**—the expansion of multicellular cyanobacteria and a boom in photosynthesis.

**Figure 8.45. $CO_2$ and Earth's Atmosphere Over Time**




Concentrations of $CO_2$ and $O_2$ in Earth's atmosphere over its history. Dramatic changes happened as plants used $CO_2$ to grow biomass and released $O_2$ during photosynthesis. Diagram by M. d'Alessio, based on data from Holland 2006

Long description of Figure 8.45.

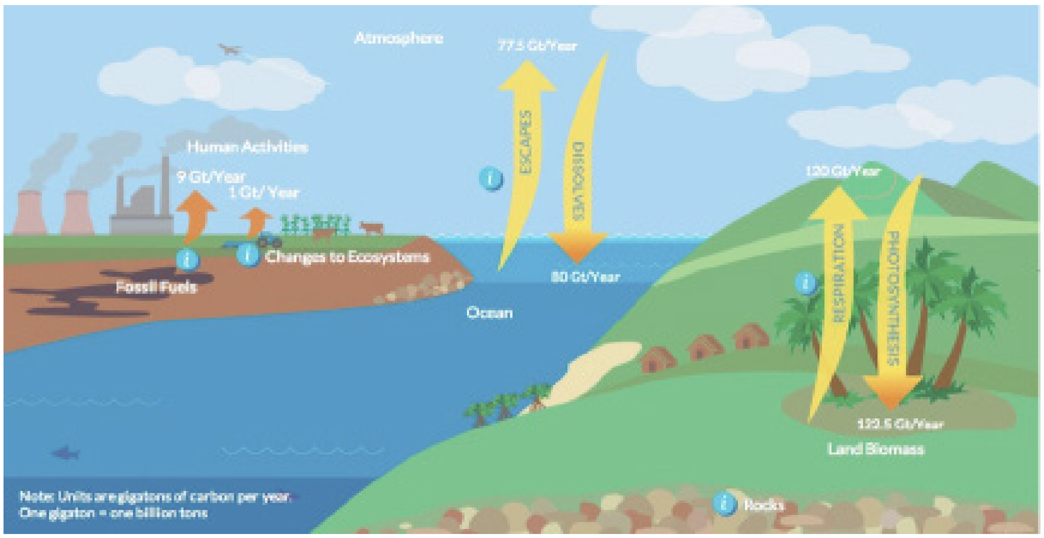
The exchange of carbon between the atmosphere and the biosphere is just one of many important interactions between Earth's **systems [CCC-4]** that involve the movement of carbon (EP&C III). In fact, one of the few additions that California made in adopting the CA NGSS was to add this sentence to the 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." Students are already familiar with cycles of matter within a system from the middle grades investigation of the water cycle (5-LS2-1, MS-ESS2-4). 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 [CCC-5]** within a closed **system [CCC-4]** because at this point in Earth's history, very little water or carbon is leaving the planet or arriving from space. We simply need to track the movement of the matter that is already here.

In the CA NGSS, students must develop a quantitative **model [SEP-2]** of the carbon cycle (HS-ESS2-6), which needs to include the following:

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 reservoirs and processes based on the amount of carbon they hold or transfer

Various representations exist for the carbon cycle, including simple diagrams like figure 8.46. Interactive animations (WGBH n.d.), hands-on experiments (see Oregon Museum of Science and Industry https://www.cde.ca.gov/ci/sc/cf/ch8.asp#link47), and kinesthetic activities build on the static illustrations to help students develop conceptual **models [SEP-2]** of the reservoirs and processes by which carbon is exchanged between these reservoirs.

**Figure 8.46. The Carbon Cycle**




*Source*: WGBH n.d.
Long description of Figure 8.46.

For example, students can develop a simple physical **model [SEP-2]** of the atmosphere–ocean **system [CCC-4]** by adding pH indicator to water in a closed container (see IS1 of the chemistry course). Students can use this model to **investigate [SEP-3]** what happens as a plant grows, a candle burns, or a person exhales through a straw into the water. They notice that pH changes as $CO_2$ from these sources 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; IS6 of the chemistry course), making Earth's oceans one of the biggest reservoirs of carbon on the planet (see table 8.9. Carbon Reservoirs and Atmospheric Flows for the relative sizes of different reservoirs). Students will **explain [SEP-6]** 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 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 balance out—the ocean absorbs about 2.5 Gt/yr more of carbon from the atmosphere. Then it releases back, causing the ocean to become more acidic. An acidic ocean can **cause [CCC-2]** major damage to plankton (which 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 **affect [CCC-2]** sea life (LS3.C). Scientists use complex computer models to calculate the expected changes in ocean chemistry based on different human activities, and the CA NGSS pushes students to use simple computer representations of **models [SEP-2]** to illustrate the relationships between different Earth **systems [CCC-4]** and to **quantify [CCC-3]** how human activities change these systems (HS-ESS3-6; see IS2 for examples).

**Table 8.9. Carbon Reservoirs and Atmospheric Flows**

| CARBON RESERVOIRS AND ATMOSPHERIC 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 by Dr. Art Sussman, courtesy of WestEd

Table 8.9 also reveals that the single largest reservoir of carbon is not in the air or water, but in rocks. How does it get there? After 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 [CCC-4]** (HS-LS1-6). Living organisms are therefore a large reservoir of carbon. When those organisms die, the carbon stored in their bodies can accumulate in layers that are buried over geologic time. Students developed models of sedimentary rock formation as part of a broader rock cycle in the middle grades (MS-ESS2-1). In high school, students will connect that model to the processes that drive the cycle (HS-ESS2-1 and HS-ESS2-3) in IS3 and IS4. Just like students tracked materials through the rock cycle in the middle grades, they will track carbon through a cycle in this instructional segment.

Heat and pressure caused by burial speed up chemical reactions within organic material embedded in rocks, slowly reorganizing 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 can draw the stages of oil formation to summarize an article presented in writing (National Energy Education Development Project 2012a). Extracting oil and gas from deep within the Earth and burning it harnesses energy that ancient plants and animals collected millions of years ago and that has been stored as chemical potential energy in materials trapped underground for millions of years. These materials are very 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 are therefore considered “nonrenewable” because we consume them much more rapidly than they form. Access to fossil fuels occurs in specific places on Earth, and California has large deposits.

### Opportunities for ELA/ELD Connections

Have students select and read a current article, from a scientific site or publication, about the different stages of oil formation and what it means to be a nonrenewable fuel source. Have students develop and use some type of note-taking guide based on the organization of the topic and subtopics in the article (cause/effect, Cornell notes, or summarizing key ideas using critical vocabulary) or a reading annotation system (highlighting main ideas or claims, underlining supporting evidence, circling critical vocabulary, and placing a question mark by unknown content).

**CA CCSS for ELA/Literacy Standards:** RST.9–12.2, 4, 5

**CA ELD Standards:** ELD.PI. 9–12.6

In the process of releasing **energy [CCC-5]**, burning fossil fuels also releases carbon into today’s atmosphere that had been removed from the atmosphere by ancient plants and animals and trapped underground for millions of years. The release of carbon occurs when CO2 forms during combustion, which is one of the reaction types that students should be able to explain in HS-PS1-2. Students’ quantitative **models [SEP-2]** of the carbon cycle must therefore include some measures of this human impact and its relative contribution to the planet's overall carbon budget. Human activities are, as of 2014, adding about 10 gigatons of carbon per year to the atmosphere, primarily from burning of fossil fuels. This means that our anthrosphere is adding more net carbon to the atmosphere than any of the other Earth **systems [CCC-4]**. Humans annually emit roughly 135 times more carbon than volcanoes, which originally supplied Earth's early atmosphere with a rich concentration of $CO_2$ (Gerlach 2011). Students will build on this understanding of both the natural cycling of carbon and their own impact on the carbon cycle in the next instructional segment about global climate.

## IS2 Earth and Space Sciences Instructional Segment 2: Climate

The topic of global climate change offers an excellent opportunity to explore the concept of planet Earth as a system (ESS2.A) and to apply science and engineering practices to a very important and highly visible societal issue. While the details of global climate change are complex and technical, the underlying science is fundamentally simple and has been known for a long time. The main ideas relate to

- the flows of energy into, within, and out of the Earth system;
- Earth's cycles of matter, especially the carbon cycle;
- the effects of human activities, especially the combustion of fossil fuels.

### EARTH AND SPACE SCIENCES INSTRUCTIONAL SEGMENT 2: CLIMATE

**Guiding Questions**

- What regulates weather and climate?
- What effects are humans having on the climate?

**Performance Expectations**

Students who demonstrate understanding can do the following:

**HS-ESS2-2.** Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. [Clarification Statement: Examples should include climate feedbacks, such as how an increase in greenhouse gases causes a rise in global temperatures that melts glacial ice, which reduces the amount of sunlight reflected from Earth's surface, increasing surface temperatures and further reducing the amount of ice. Examples could also be taken from other system interactions, such as how the loss of ground vegetation causes an increase in water runoff and soil erosion; how dammed rivers increase groundwater recharge, decrease sediment transport, and increase coastal erosion; or how the loss of wetlands causes a decrease in local humidity that further reduces the wetland extent.]