Mathematical Models of Chemical Energy

Students observed differences in the relative strength of different types of bonds and attractions. Would they expect these differences to correlate to different amounts of energy stored in these bonds? Students can **analyze data [SEP-4]** about binding energy from published data tables or from their own investigations to look for **patterns [CCC-1]**.

The assessment boundary of HS-PS1-4 states that students will not be assessed within the CA NGSS on calculations of total bond energy in chemical reactions. Even though students' models of bond energy are only required to be conceptual, these calculations can provide more advanced students opportunities to apply and improve their stoichiometry skills. For example, students can predict the temperature change when they react a certain mass of reactants.

IS5 Chemistry in the Earth System Instructional Segment 5: Chemistry of Climate Change

In this instructional segment students apply their understanding of chemical reactions to global climate. Many of the key issues illustrated build on concepts related to thermodynamics and **energy [CCC-5]** balances within systems (from IS2) and the products of chemical reactions (from IS4). This instructional segment focuses on the natural cycle of carbon and human impacts on it (EP&Cs III, IV). Since the carbon cycle is intricately linked to all life on Earth, this instructional segment integrates with life science units in which students explore the impact of this physical science concept on the Earth system.

CHEMISTRY IN THE EARTH SYSTEM INSTRUCTIONAL SEGMENT 5: CHEMISTRY OF CLIMATE CHANGE

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.]

CHEMISTRY IN THE EARTH SYSTEM INSTRUCTIONAL SEGMENT 5: CHEMISTRY OF CLIMATE CHANGE

HS-ESS2-4. Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] *[Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.]*

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.]

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.* [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems. [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] *[Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.]*

HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.* [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] *[Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.]*

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

CHEMISTRY IN THE EARTH SYSTEM INSTRUCTIONAL SEGMENT 5: CHEMISTRY OF CLIMATE CHANGE

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 [SEP-4] Analyzing and Interpreting Data [SEP-5] Using Mathematics and Computational Thinking [SEP-7] Engaging in Argument from Evidence	ESS1.B: Earth and the Solar System ESS2.A: Earth Materials and Systems ESS2.D: Weather and Climate PS3.B: Conservation of Energy and Energy Transfer PS3.D: Energy and Chemical Processes in Everyday Life PS4.B: Electromagnetic Radiation ESS3.A: Natural Resources ESS3.D: Global Climate Change	[CCC-2] Cause and Effect: Mechanism and Explanation [CCC-4] Systems and System Models [CCC-5] Energy and Matter: Flows, Cycles, and Conservation [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 V Decisions affecting resources and natural systems are complex and involve many factors.

CA CCSS Math Connections: N-Q.1; F-LE.1b, c; S-ID.6, 7; MP. 1, MP. 2, MP. 3, MP.4

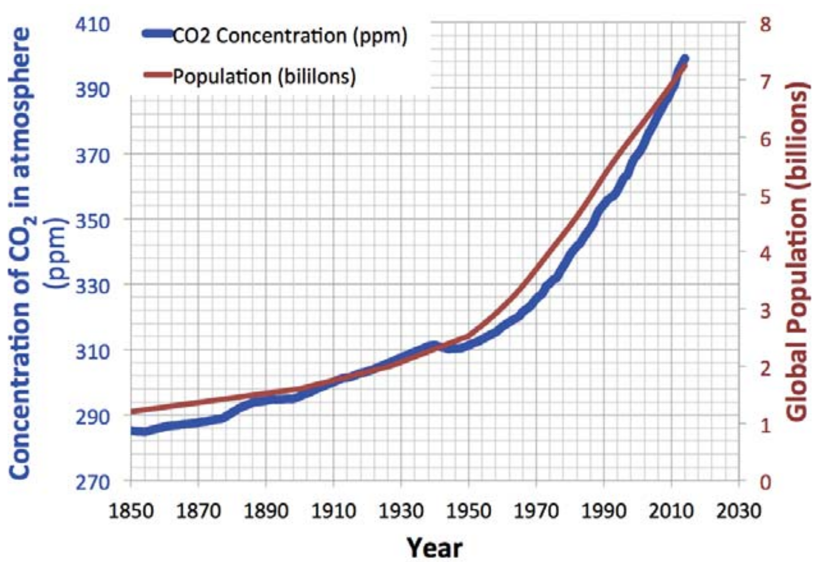
CA CCSS for ELA/Literacy Connections: SL.9–10.1c–d, SL.11–12.1c–d; WHST.9–10.4, 6, 9, 10; RST.9–10.1, 7, 9

CA ELD Connections: ELD.PI.9–10.1, 2, 3, 6a–b, 11a; ELD.PII.9–10.1

Students revisit the introductory activity in IS1 on combustion through the lens of their new mental **models [SEP-2]**. Students likely have prior knowledge that combustion requires oxygen and gives off **energy [CCC-5]** in the same way as aerobic respiration. In fact, looking at the initial and final products, combustion reactions are identical to the aerobic reaction shown in figure 7.28. The energy obtained by chemical reactions inside our bodies is the same as the energy released in the combustion reaction in food calorimetry, which is why we can burn food to figure out how much energy it will give us. They can also understand why a match or lighter is needed to provide the initial activation energy to start the chemical reaction. Students also likely have prior knowledge that they exhale CO_2, and by feeling the moisture in their breath, they can realize that they also exhale water in a gaseous form. Despite the fact that they cannot see either of these gases, both have mass. When people exhale, they are losing weight (and in fact, vigorous exercise that makes them exhale more will indeed allow them to lose more weight). In the food calorimetry experiment, students measured the mass of the food at the beginning and compared it to the remaining mass and noticed that some of the mass disappeared. They can now revise their model to show that it was released as hot CO_2 and H_2O gas. Its mass flowed out of the smaller **system [CCC-4]** of their laboratory investigation and into the air of the room around it (much like mass flowed into the system to provide the oxygen for the reactants). If they considered the entire room as their **system [CCC-4]** and were able to measure its mass, they would have seen that it remained unchanged during the experiment.

Combustion can occur in a range of materials besides food. Combustion that involves molecules made entirely of carbon, hydrogen, and oxygen (hydrocarbons) will always release the same reaction products (albeit in different ratios; see IS5). Most of the fuels used in everyday life are hydrocarbons, including logs of firewood, natural gas on stovetops, and gasoline in cars. All of these hydrocarbons produce carbon dioxide as they provide the energy people use every day. In fact, as more and more people inhabit the planet, more carbon dioxide is being emitted into the atmosphere every day, where it accumulates (figure 7.29).

Figure 7.29. Relationship Between Global Population and Atmospheric CO_2



Relationship between global population and atmospheric CO_2. With a few notable economic slowdowns, more people equates to more emissions, which raises the concentration of CO_2 in our atmosphere. In recent years, global population is slowing its growth, but changes in lifestyles that burn more hydrocarbons for energy are causing emissions to continue to grow. *Source*: M. d'Alessio using data from NASA n.d.; National Oceanic and Atmospheric Administration 2016a; United Nations, Department of Economic and Social Affairs, Population Division 2015; United States Census Bureau 2016

The carbon dioxide produced by combustion plays a crucial role in regulating Earth's climate system (EP&C IV, see also EEI curriculum unit on the *Greenhouse Effect on Natural Systems* at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link24). In this instructional segment, students apply their understandings of conservation of **energy [CCC-5]** and heat flow (from IS2) and interactions between **energy and matter [CCC-5]** (from the High School Three-Course Model Physics of the Universe course) to understand this role. The topic of global climate change offers an excellent opportunity to explore the concept of planet Earth as a **system [CCC-4]** (ESS2.A), and to apply science and engineering practices to a very important and highly visible societal issue (HS-ETS1-1). While the details of global climate change can be very complex and technical, the underlying science has been known for a long time and is quite understandable. The main ideas relate to

- the **flows of energy [CCC-5]** into, within, and out of the Earth system;
- Earth's **cycles of matter [CCC-5]**, especially the carbon cycle;
- the **effects [CCC-2]** of human activities, especially the combustion of fossil fuels.

Opportunities for ELA/ELD Connections

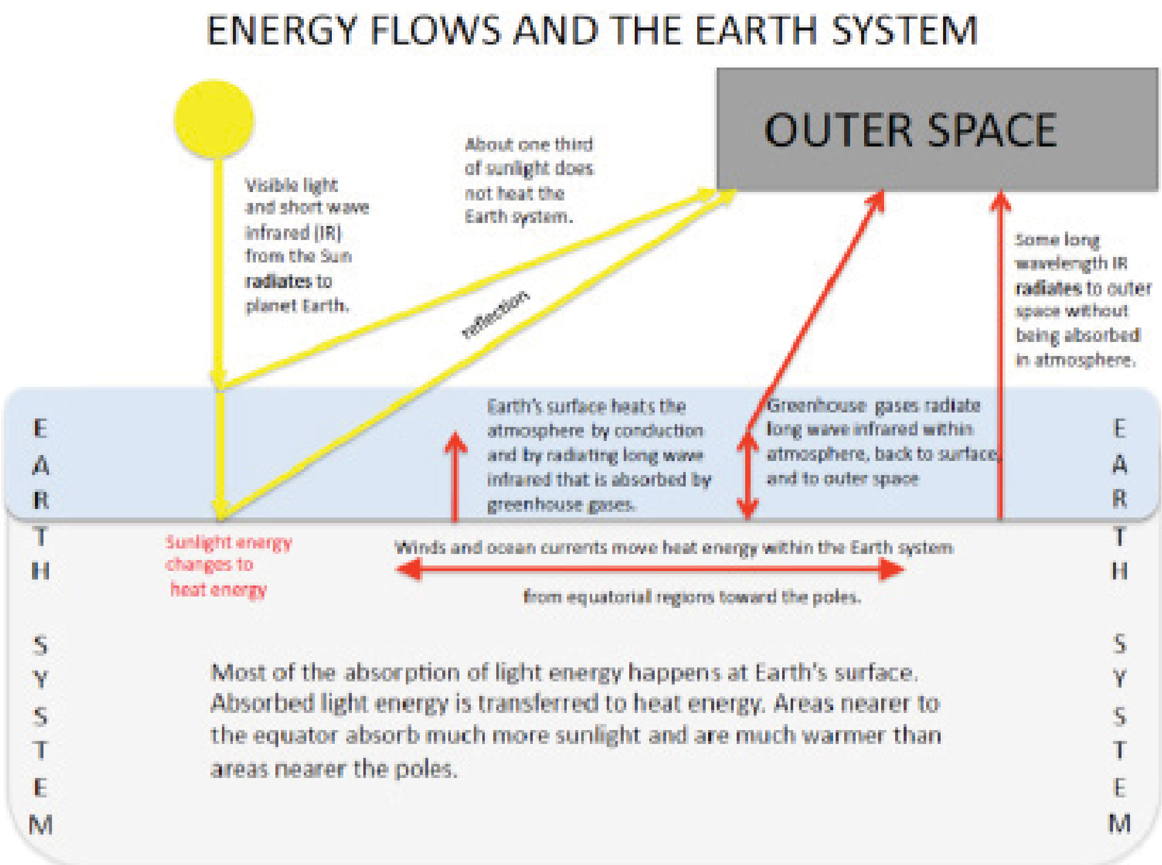
Students select and read a current article, from a scientific site or publication, about an example of how a change to the Earth's surface can cause changes to the global climate. The teacher may want to focus articles on topics included in IS5, such as greenhouse gases, deforestation, damming rivers, loss of wetlands, or burning fossil fuels. Encourage students to develop and organize their notes based on the organization of the topic and subtopics in the articles (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

The performance expectations in this instructional segment build on significant work on disciplinary core ideas related to weather and climate (ESS2.D) in the middle grades standards in which students learned that ocean and atmospheric currents are the equivalent of Earth's circulation system, transferring heat from the warm equator towards the cooler poles and bringing the planet closer to thermal balance (MS-ESS3-4, now understood more deeply through HS-PS3-4). Students have also learned about the role that moving air masses play in determining short-term weather (MS-ESS2-5). They have been introduced to climate change and that global average temperatures have risen in the last century and have investigated possible causes (MS-ESS2-6). In this instructional segment they must delve into a more sophisticated understanding of Earth's **energy [CCC-5]** balance and its relationship to the global carbon **cycle [CCC-5]**.

The crosscutting concept of **systems [CCC-4]** is crucial to understanding Earth's climate. When scientists think about a system, they need to consider the **energy and matter [CCC-5]** that flow into or out of the system, as well as the inner workings of the system. In some systems, it is hard to decide where to draw the boundaries between what is considered inside the system and what is considered outside (such as the example of the missing mass in the food calorimetry investigation that was not really missing if we considered the room as a system). Earth's climate, however, does not present such a challenge if we consider the entire planet Earth as a system. Earth is somewhat isolated out in space, with relatively little matter entering or leaving the planet. **Energy [CCC-5]**, however, flows into and out of the Earth (figure 7.30).

Figure 7.30. Energy Flows in the Earth System



Energy flows in the Earth system, an illustration of a systems model. Diagram by Dr. Art Sussman, courtesy of WestEd.

Students can make a conceptual model of Earth's energy budget using an analogy of the line for a ride at an amusement park. The constant stream of eager visitors arriving at the end of the line represents solar radiation. As visitors get on the ride at the front of the line, they act like energy radiating out into space. Earth's global average temperature measures the amount of heat stored internally in Earth's system and so it is like the number of people waiting in line at any given time. The line will remain the same length if people get on the ride as quickly as new people arrive at the end of the line. Earth's temperature will remain **stable [CCC-7]** as long as the energy input and output remain unchanged.

Earth's **energy [CCC-5]** input comes almost entirely from the Sun. While there is a small amount of radioactive decay within Earth's interior that generates heat, the flow of solar energy to Earth's surface is about 4,000 times greater than the flow of energy from Earth's interior to its surface. Relatively small changes in the solar input can result in an

Ice Age or the melting of all of Earth's ice, much like the sudden arrival of a large group at an amusement ride can cause the line to quickly grow longer. The line will stabilize at this new length (without continuing to grow) as long as the influx of people returns back to its original rate. Planets can do the same thing, maintaining their temperature at a new value after a temporary disturbance.

Most of the sunlight that reaches Earth is absorbed and transformed to thermal **energy [CCC-5]**. If there were no atmosphere to hold that energy, it would radiate right back into space as infrared radiation (like an unpopular amusement park ride where people get on as soon as they arrive because there is no line). Gases in the atmosphere, such as CO_2, absorb infrared energy heading into space and **cause [CCC-2]** it to remain within the Earth system for a longer period of time. Because these gases have the same effect as a greenhouse where heat is trapped inside the system, gases like CO_2 are referred to as greenhouse gases. Calculations by scientists show that if Earth had no greenhouse gases, its surface temperature would be near 0°F (or -18°C) instead of its current value of a much warmer 59°F (15°C). The energy coming into the Earth is still balanced almost exactly by what is leaving the planet but there is enough heat trapped in the system to allow life to thrive (like the amusement park ride whose line is always the same length).

By increasing the amount of greenhouse gases in the atmosphere, human activities are increasing the greenhouse effect and warming Earth's climate. In a given year, less energy leaves Earth than arrives. It's like one of the seatbelts breaks on the amusement park ride and fewer people are able to get on the ride at a time. All of a sudden, the line gets longer and longer as new people arrive because people are not able to leave the line as quickly at the front. At the amusement park, this might lead to impatient children. On Earth, the imbalance in energy flows leads to an overall rise in average temperature.

Chemistry in the Earth System Snapshot 7.8: Structure and Function in Greenhouse Gases

Anchoring phenomenon: A methane leak from a natural gas storage facility is considered by some to be the largest climate disaster in US history.

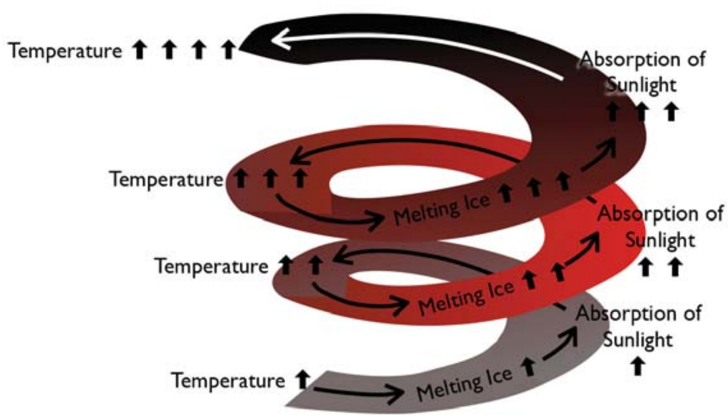
Motivated by the recent news story about a major methane leak in California, Mr. P's students were **asking questions [SEP-1]** about what other gases can trap infrared energy. Mr. P wanted his honors chemistry students to develop **models [SEP-2]** of how greenhouse gases absorb infrared energy. They began with a basic computer simulation (see PhET, *The Greenhouse Effect* at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link25) showing how molecules can absorb energy as the atoms in the bond vibrate towards and away from one another.

Investigative phenomenon: Some molecules absorb infrared energy more than other molecules.

The simulator demonstrates the effects of different molecules with different bonds and different **structures [CCC-6]**. Mr. P provided information about molecular structures and the qualitative principles about how repulsion between valence electrons helps control the structure of molecules. These structures have a strong influence on the vibrational energy molecules can absorb. Mr. P had students use evidence from the simulator to **construct an argument [SEP-7]** about why methane, water vapor, and carbon dioxide are strong greenhouse gases while oxygen and nitrogen are not. This phenomenon was a more advanced demonstration of how atomic-scale properties can influence bulk behavior (HS-PS1-3).

Amusement parks and planets are **systems [CCC-4]** with complicated inner workings. When lines for one ride at an amusement park get too long, visitors inside the park may respond by going to another ride or park operators may add additional workers or cars to help move people through more quickly. Similar changes happen in Earth's system of systems. While the greenhouse effect seems like a simple **cause and effect [CCC-2]** relationship viewed from outside the system, interactions *within* the system can often give rise to more complicated chains of cause and effect referred to as *feedbacks*. Climate scientists are particularly concerned about feedback effects that could increase the amount and rate of global climate change. One example is that global warming is clearly reducing the amount of ice on our planet (figure 7.31). Glaciers around the world are shrinking in size and even disappearing. The amount of ice covering the ocean in summer and fall is also shrinking. As the ice melts, the surface beneath it is darker in color and absorbs more incoming sunlight. More absorption causes more heating, and this heating causes even more absorption of sunlight. This kind of feedback loop amplifies or reinforces the change, and the distinction between **cause and effect [CCC-2]** begins to blur as each effect causes more change. The clarification statements in the CA NGSS and many scientists use the term *positive feedback*, but this term should be replaced because it leads to confusion—many *reinforcing feedbacks* have very negative outcomes.

Figure 7.31. A Reinforcing Feedback in Earth's Climate

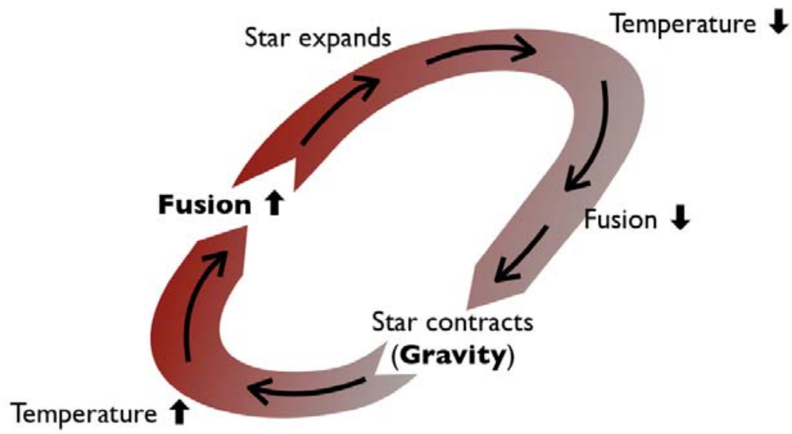


A reinforcing feedback in Earth's climate system. As the planet warms, more ice will melt, which will expose darker ground surfaces that absorb more sunlight, which will in turn make temperatures rise even more. Diagram by M. d'Alessio and A. Sussman.

A *counterbalancing feedback loop* reduces the amount of change (figure 7.32). For example, warmer temperatures cause more water to evaporate, which enables more clouds to form. Since clouds reflect sunlight back into space, more clouds cause more incoming solar energy to be reflected before it has a chance to be absorbed by the planet. This causes decreasing global temperatures. More warming could cause more cloud formation and reflection, which would then lead to less warming again.[9] These changes are opposite and can balance each other out.

9. Even though this example describes a counterbalancing feedback involving clouds, clouds are also involved in a reinforcing feedback where they trap more heat, causing more evaporation, and more clouds that trap more heat. Both of these mechanisms occur on Earth. The question researchers are currently trying to answer is, "Which feedback loop is more powerful, reinforcing or counterbalancing?" **Cause and effect [CCC-2]** gets very complicated in the Earth system.

Figure 7.32. A Counterbalancing Feedback in Earth's Climate System



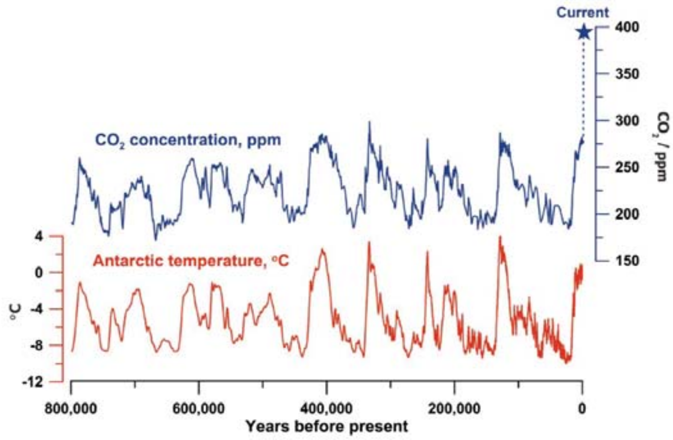
Temperature changes cause changes to the number of clouds because of evaporation. Clouds, in turn, reflect light. Diagram by M. d'Alessio and A. Sussman.

Scientists discover these complicated interactions between different components of Earth's **systems [CCC-4]** by looking for trends and **patterns [CCC-1]** in climate data. The CA NGSS have a strong emphasis on data analysis, especially in the sections related to weather and climate:

> An important aspect of Earth and space science involves making inferences about events in Earth's history based on a data record that is increasingly incomplete that farther you go back in time … . Students can understand the analysis and interpretation of different kinds of geoscience data. Allow students to construct explanations for the many factors that drive climate change over a wide range of time scales. (NGSS Lead States 2013d)

Some of the strongest **evidence [SEP-7]** about our changing climate comes from ice-core records (figure 7.33). As snow accumulates over time in glaciers around the globe, it traps both the water that recently fell as precipitation and air bubbles. These air bubbles act as tiny time capsules that allow scientists to study actual samples of the ancient atmosphere. Since snow and ice build up seasonally, the timing of each layer of ice and its trapped air bubbles can be counted like tree rings. Scientists make detailed chemical analyses of the water to reconstruct the global average temperature. Details of how this isotopic analysis provides a proxy for global temperature is beyond the scope of high school performance expectations, but is a fascinating example of physics, chemistry, and earth science working together.

Figure 7.33. Temperature and Carbon Dioxide Over the Last 800,000 Years



Source: The Royal Society 2014

Chemistry in the Earth System Snapshot 7.9: Trends and Patterns in Modern Atmospheric CO_2 Levels

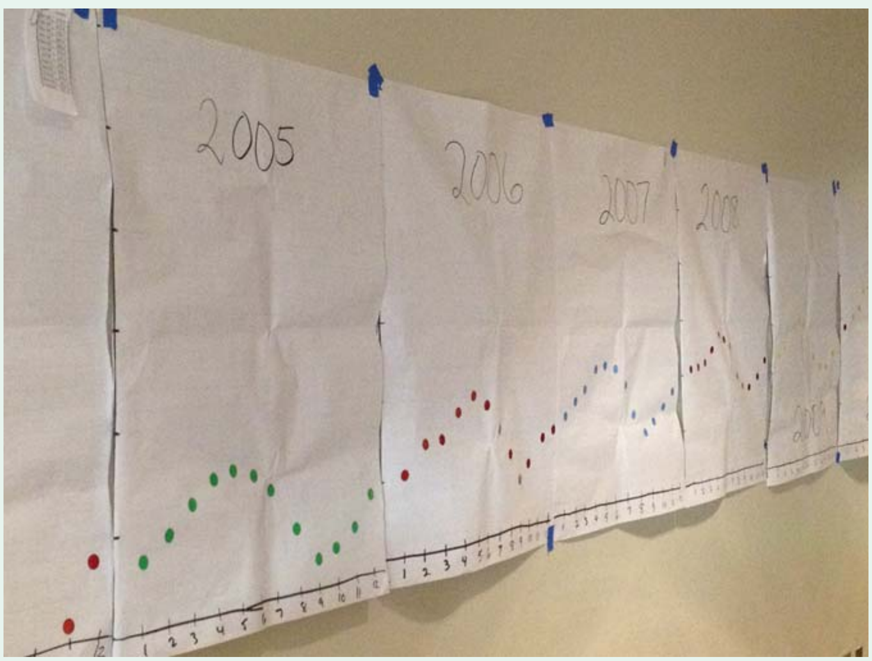
Investigative phenomenon: Atmospheric CO_2 consistently rises and falls with the seasons but also is consistently rising from year to year.

Ms. R wanted the students to get a sense for how much CO_2 there was and how it has changed over time. She introduced the units of parts per million (ppm), relating it to the familiar concept of percent (parts per hundred). She also used her city, which had almost a million people in it, as an analogy in which the school's population of 2,700 equates to 2,700 ppm of the city. CO_2 molecules in the atmosphere are even rarer than that, at about 400 ppm. Ms. R distributed a poster-size piece of graph paper to each team, along with sticker dots and a table showing one year's worth of atmospheric CO_2 measurements recorded each month at the top of Mauna Loa in Hawaii (see NOAA, Trends in Atmospheric CO_2 at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link26). Each team placed stickers to plot data from a different year, but all graph papers had identical axes with identical scales. She asked students to identify trends and **patterns [CCC-1]** they saw in their one year of data and almost every group indicated that the graph went up and down once over the course of the year, with the peak value sometime in the middle of the year. Students associated the changes with the seasons since they repeat once a year. The pattern of fluctuating CO_2 relates to the growth of vegetation; since there is more vegetated land area in the northern hemisphere, the consumption of CO_2 by plants varies as seasons shift from the productive summer months in the northern hemisphere to summer in the southern hemisphere.

Chemistry in the Earth System Snapshot 7.9: Trends and Patterns in Modern Atmospheric CO_2 Levels

The class taped their graphs side by side to the wall in sequence so that they create one long time-series graph. Each class period was assigned additional data from different years and by the end of the school day, her classes had filled the entire length of the hallway with 35 years of data (figure 7.34). She showed an interactive visualization of global CO_2 data (see NOAA, History of atmospheric carbon dioxide from 800,000 years ago until January, 2014 at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link27) so that students could observe the trend using a more dynamic visualization, and she asked students to **evaluate [SEP-8]** the benefits of using each format. Ms. R began the next class period having students walk along the entire graph. She asked each team of students to **analyze [SEP-4]** the past data and draw a graph predicting the next five years, extrapolating both the long-term trend of increasing CO_2 and the annual variation. She had them calculate the year in which atmospheric CO_2 would reach 540 ppm (approximately double the pre-industrial CO_2 levels), assuming that current trends continue. When students compared their predictions, she had them discuss assumptions they made about how quickly the CO_2 would increase (some groups assumed a linear increase, while others noticed that the curve seemed to be rising more and more each year). She related back to this discussion when the class researched energy resources.

Figure 7.34. Time Series of CO_2 on a Classroom Wall



Picture by M. d'Alessio

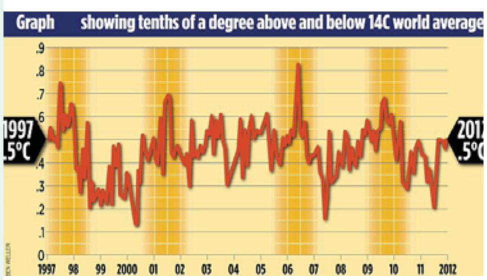
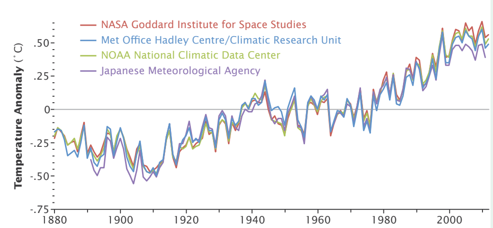
The temperature record from the last half million years reveals some dramatic **patterns [CCC-1]** as temperatures go up and down with a periodicity of about 100,000 years, each low temperature an ice age (National Oceanic and Atmospheric Administration, National Climatic Data Center 2008). When students examine such data, they should be able to **ask questions [SEP-1]** about which parts of the climate **system [CCC-4]** might have **caused [CCC-2]** these changes. If students compare temperature reconstructions with reconstructions of the amount of **energy [CCC-5]** received from the Sun (which varies as the Earth's orbit wobbles and the Sun's energy output changes cyclically over time), they will discover that the data sets have a similar **pattern [CCC-1]**: many warm periods in the ice core data correspond to periods of higher solar energy input (EP&C II). This seems quite reasonable because the Sun's input should influence our temperature. However, there are also time intervals where the Earth was hot that do not correspond to high solar energy. The **pattern [CCC-1]** in the history of the concentration of CO_2 in Earth's atmosphere and temperatures is very similar; the two are highly correlated. This correlation is a key piece of **evidence [SEP-7]** that CO_2 also plays a role in affecting Earth's temperature. In a classroom, this correlation can motivate a discussion of Earth's energy budget and the greenhouse effect.

Chemistry in the Earth System Snapshot 7.10: Letters to the Editor and Evaluating Climate Change Graphs

Anchoring phenomenon: Two news stories about the same scientific research have different headlines and are supported by different graphs of the same data set.

Earlier in the year, Ms. Q had her students read about how to **evaluate [SEP-8]** the scientific arguments made in media sources using a checklist called the Science Toolkit (see UC Museum of Paleontology at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link28). To begin this unit, she had them read two Internet articles with radically different headlines that each used a graph of global temperature as **evidence [SEP-7]**. Students worked in pairs to evaluate the two articles based on the criteria outlined in the Science Toolkit. Walking around the room, Fernando asked her about the sources: "This article is from NASA, but what is the Weekly Star? Who wrote it?" She encouraged him to do a quick internet search about the newspaper's editorial board. A bit later, Cynthia mentioned that both articles use graphs (figure 7.35), but they look totally different.

Figure 7.35. Two Representations of the Same Data Set by Different Sources

<table>
<tr><td>Global warming stopped 16 years ago, reveals Met Office report quietly released … and here is the chart to prove it</td><td>Long-Term Global Warming Trend Continues</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Weekly Star (fictitious)</td><td>NASA's Earth Observatory 2013</td></tr>
</table>

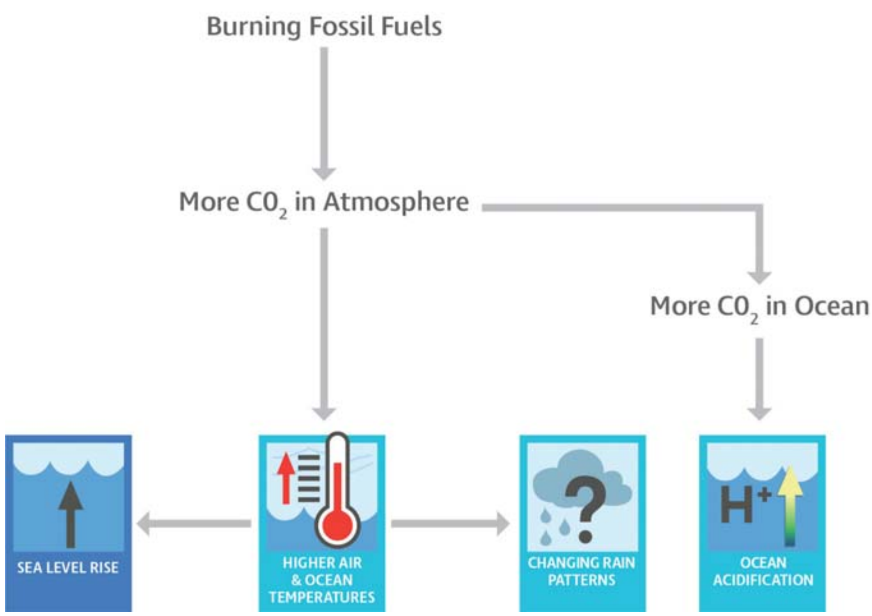
Ms. Q then asked the whole class to discuss the graphs and construct an **argument [SEP-7]** about which graph contained stronger **evidence [SEP-7]**. Ali noticed that one graph included a much longer span of time, "and climate is supposed to be a long-term thing." Jenni said, "This graph has four lines from scientists all over the world that all show the same ups and downs. That shows science is repeatable, and I like that." To conclude the lesson, students wrote letters to the editor in response to the *Weekly Star* article articulating their **argument [SEP-7]**.

In the CA NGSS, students combine their general understanding with **computational thinking [SEP-5]** by using simple computer simulations (see PhET, *The Greenhouse Effect* at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link29) to model the **flow of energy [CCC-5]** into and out of the Earth and the role that CO_2 and other greenhouse gases play in that process (HS-ESS2-4). Scientists use simulators of Earth's climate called global climate **models [SEP-2]** (GCMs) that are much more detailed and include many other processes and interactions between Earth **systems [CCC-4]**. The assessment boundary of HS-ESS3-6 states that students should not be required to run their own **models [SEP-2]**, though simplified versions of GCMs exist for educational purposes (see Columbia University, Educational Global Climate Modeling Web site at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link30 and Java Climate Model at http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link31). The advantage of these models is that they enable students to turn on and off different parts of the Earth system to see how they affect the climate. For example, students can compare a model of the Earth without the biosphere to a model that includes the biosphere. As CO_2 increases in the atmosphere, plant growth decreases the impact of global warming (a counterbalancing feedback). Comparing the predictions of a computer model that allows ice to melt with one in which ice is not allowed to melt is another form of **analyzing and interpreting data [SEP-4]** and can help build students' mental **models [SEP-2]** of the climate system. **Models [SEP-2]**, as defined in the CA NGSS, represent a system that allows for predicting outcomes, so the output of a computational model can sometimes be more useful at anticipating the future than simply examining historical data. Ultimately, students need to be able to communicate their mental model by describing specific feedbacks in the Earth system using an argument (HS-ESS2-2). In a classroom, various student teams could examine different elements of an Earth system using teacher-provided results of model runs or creating their own with educational GCMs. They could then compile brief reports to share with their classmates about the **effects [CCC-2]** of these different processes on global climate.

Another crucial observation about Earth's climate is that the concentration of CO_2 and other greenhouse gases in our atmosphere has been growing steadily since the dawn of the industrial era. Students should be able to make connections to the previous instructional segment and know that the vast majority of this increase comes from humans' extraction and combustion of fossil fuels. GCMs allow scientists and students to see how the climate is expected to change as greenhouse gases trap more energy in the atmosphere. Because of the linkages between different components of Earth's **systems [CCC-4]**, these impacts extend to all of Earth's systems. Figure 7.36 shows a few of these linkages. In a classroom, different student groups could **obtain information [SEP-8]** from library and Internet resources to construct a report on the impact predicted for different parts of the world so that the class as a whole could create a product to share with the rest of their school that summarizes the global impacts (HS-ESS3-6).

EEI Curriculum units—*The Life and Times of Carbon* and *The Greenhouse Effect on Natural Systems* (http://www.cde.ca.gov/ci/sc/cf/ch7.asp#link32)—explore human practices that can influence the global carbon cycle and how human activities affect quantities of greenhouse gases. These units can be used in conjunction with this instructional segment to provide materials that examine EP&Cs III and IV.

Figure 7.36. Cause and Effect Chains Illustrate How Human Activities Affect Natural Systems

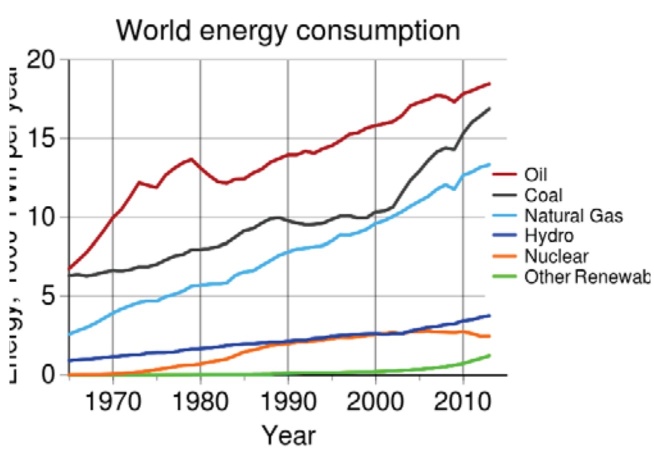


One example of how humans affect the climate, which impacts all parts of Earth's systems. Illustration by Dr. Art Sussman, WestEd, and Lisa Rosenthal, WGBH.

Engineering Connection: The Chemistry of Global Energy Supplies

Figure 7.37 graphs trends in world energy consumption and illustrates that the three major sources of energy worldwide are fossil fuels (oil, coal, and natural gas). Students can obtain information about the impacts of fossil fuels on natural systems that arise because harnessing the energy from fossil fuels also disrupts global cycles of matter in the Earth system (ESS2.A; EP&C III, IV). Climate change results from rising levels of greenhouse gases (e.g., carbon dioxide, methane, and nitrous oxide). Carbon dioxide is released when fossil fuels react with oxygen during combustion, and students can **obtain information [SEP-8]** about chemical methods of carbon sequestration that are current research topics. Natural gas is primarily methane, which can leak into the atmosphere during production, processing, transport, storage, and distribution. Students can **obtain information [SEP-8]** about cutting-edge technologies to monitor leaks in real time. Acid rain results from nitrogen and sulfur oxides commonly released during combustion of sulfur rich fuels such as coal. Students could **obtain information [SEP-8]** about the chemical technology used to minimize the release of sulfur dioxide. Since these systems were mandated, acid rain has substantially declined in the United States. Smog involves reactions between tailpipe emissions of cars and the air (with sunlight adding some of the energy to break chemical bonds). Students could also **obtain information [SEP-8]** about how improvements to the combustion efficiency of cars have reduced smog. Students should do more than just explain the chemical reactions in each of these processes. They should consider the criteria and constraints about society's need for clean air and clean water along with the need for more energy (HS-ETS1-1; EP&C V). Students should be encouraged to break down the problem into smaller, more manageable problems that can be solved through [chemical] engineering (HS-ETS1-2).

Figure 7.37. What Fuels Provide the World's Energy?



Source: BP 2016