Chemistry in the Earth System: Unit 4

Carbon Dioxide and Climate Change

Background for Teachers and Instructional Suggestions

In this instructional segment, students will learn how elements combine to form new compounds, the forces that hold them together, the forces between particles and molecules, and the ***energy*** needed to break or form bonds. Students should take what was learned in previous instructional segments to apply to the principles of bonding. In the traditional approach, students were taught and memorized, that ionic bonds result from the transfer of electrons from one atom to another and covalent bonds from the sharing of electrons between two atoms. Students were then presented with differences in the two types of bonding. By contrast the *CA NGSS* approach encourages students to accumulate evidence regarding how substances behave on their own and with other substances, and then construct cognitive **models** based on such **evidence**. The *CA NGSS* requires students to explain their reasoning for applying evidence to their **models**. In so doing, they gain experience with the physical and chemical properties that allow them to make inferences regarding the forces and ***energy*** associated with particles and molecules.

An understanding of chemical structure is foundational to understanding properties of matter, particularly those involved in chemical reactions that are key to a myriad of physical and biological processes. ***Energy*** is the capacity to perform work and is necessary to ***cause*** the motion and interaction of atoms and molecules. Once students understand atomic structure, and are able to predict basic properties based upon the position of an element in the periodic table, they are ready to investigate chemical energetics. *HS-PS1-4* requires students to **develop models** that illustrate the release or absorption of energy from chemical reactions. Students can use graphs, diagrams and drawings to **model *changes*** in total bond energy, such as those shown in Figure 8. Examples of a range of graphs, diagrams and drawings developed by

scientists as models of changes in total bond energy. Students develop their own mental models for energy changes in chemical reactions that they can express in pictorial models that may look like these.

, and use these tools to explain energy changes accompanying chemical reactions. Note that the models in Figure 8, like many pictorial models that appear in textbooks, were drafted by scientists. The models that those scientists produced when they were students were unlikely as simple and complete as these final products, but they refined their models over years. Revising models is an integral part of the nature of science.

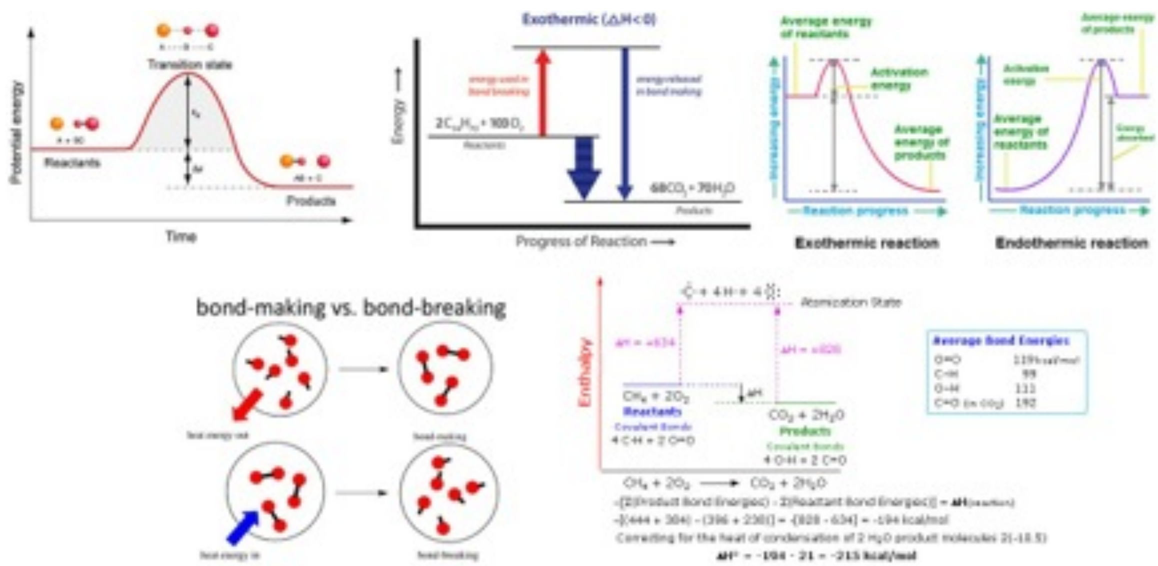

Figure 8. Examples of a range of graphs, diagrams and drawings developed by scientists as models of changes in total bond energy. Students develop their own mental models for energy changes in chemical reactions that they can express in pictorial models that may look like these.

In students' **models** of chemical reactions, original chemical bonds are broken and new bonds form. Each of these ***changes*** affects the distribution of energy within the chemical ***system***, so they must extend their model to include these ***energy flows***. Energy conservation in chemical processes is, however, an abstract concept and must be discussed and developed with care. Students **carryout investigations** to collect and **analyze data** (both quantitative and descriptive observations) to discover that some reactions appear to release energy to their environment while others absorb it. In a more detailed model of the ***energy flow***, however, all chemical reactions both absorb and release energy, just in differing amounts. Chemical bonds are not tangible objects but actually the name given to a situation where two atoms are attracted together by electric forces. Chemical reactions involve separating two atoms (requiring work to overcome their attraction just like lifting a heavy load against the force of gravity) and bringing a different combination of the atoms closer together (which releases ***energy***, much like a falling ball converts gravitational potential energy to kinetic energy as it is attracted to the Earth and moves closer to it). Whether or not a chemical reaction gives off energy overall depends on the relative magnitudes of these two energies. Chemists usually refer to the potential energy related to the relative position of two interacting atoms in a chemical bond as the 'bond energy.' By comparing the bond energy of the products with the bond energy of the reactants, students can construct **mathematical models** of the energy in the system and predict whether or not energy will be absorbed or released. A simple investigation to verify this **model** could include dissolving salt in water where the chemical bond between sodium and chlorine is broken (requiring lots of energy) and the attraction between water and the sodium and chlorine ions is tenuous and the atoms don't remain close together (releasing relatively little potential energy). The temperature of water goes down when salt dissolves in it. Another example is the classic set of reactions that comprise photosynthesis and respiration. The complex biochemistry of photosynthetic reactions is not necessary at this stage, but the fact that the formation of biomass from carbon dioxide and water requires energy input is an important understanding that has been stressed in earlier grades. That energy input can now can be understood in greater detail given comprehension of the energetics of chemical bonds (Figure 9). The equations in Figure 9 are the net result of a number of other chemical reactions along the way (the various cycles involving ATP and other intermediate molecules). The reason these other reactions are required is because of the energy required to break bonds of the reactants apart (often called the activation energy, which some models in Figure 8 depict as a temporary increase in energy during the chemical reaction). The intermediate stages involve certain proteins encoded by DNA to re-orient the molecules and reduce the activation energy.

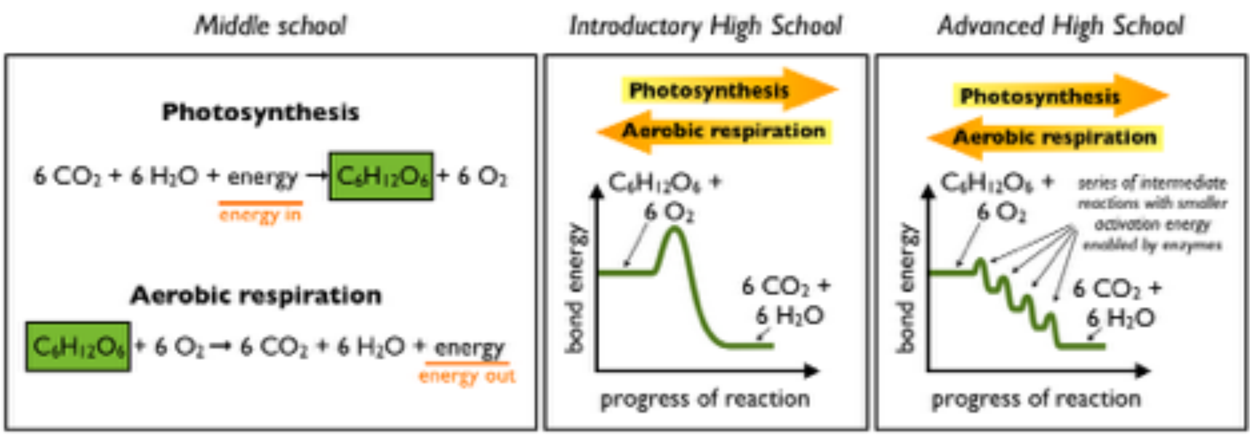

Figure 9. Illustration of how students' models of the energy in chemical reactions can be revised to be more detailed over time. Simplified equations for photosynthesis and aerobic respiration show a middle grade model of energy in chemical reactions (left; note that middle grade students are not assessed on balancing chemical equations). An introductory high school model of energy changes during these chemical reactions includes details about bonding energy (middle). A more advanced model that integrates core ideas from life science shows a series of intermediate chemical reactions inside cells each with a smaller activation energy (right). Image Credit: (CC-BY-NC-SA) by M. d'Alessio

Snapshot: Chemical Energetics

The ability to **develop and use models** is emphasized as a science and engineering practice in NGSS, as well as a standard for mathematical practice in the Common Core State Standards. CCSS math practice-4 (MP-4) states that high school students should be able *to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas.* Having taught for a number of years, Mr. S realizes that his chemistry students often memorize diagrams and charts presented in the textbook, developing little appreciation of what such models exemplify and limited understanding of the complex phenomena that they represent.

In an effort to build the science and engineering practice of developing and using models, while addressing the expectations of **HS-PS1-4** (*Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy*), Mr. S develops a two-day lesson as part of a larger instructional segment on chemical reactions to help students discover the power and limitations of models. At the beginning of class, Mr. S distributes reusable hot and cold packs, used to treat sports injuries, and instructs his students to flex the bags, feel the change in temperature, measure the temperature change using infrared thermometers obtained from the local building supply store, and record these change in a collaborative online database. Despite variations in individual recordings among classmates, students will notice similar ***patterns*** in the temperature gains or losses for the hot and cold packs.

California ELA Vocabulary and Concept Development Standard 1.2 for grades 11-12 requires students to *apply knowledge of Greek, Latin, and Anglo-Saxon roots and affixes to draw inferences concerning the meaning of scientific and mathematical terminology*. Mr. H. writes the words “endothermic” and “exothermic” on the board and asks students to enter as many words as they can know or can find that use the roots: *end*-, *ex*- and *therm*- into an online form. Within a couple of minutes, the collaborative cloud-based list has grown to several dozen words, including: *endosperm, endocrine, endothermic, endemic; exoskeleton, exocrine, exotic, extraterrestrial, extinct, exit; and thermometer, thermistor, ectotherm, thermophilic, thermoregulationl.* Mr. S then prompts his students to predict the meaning of these roots based upon the meanings shared by the words that contain them. Mr. S monitors their predictions as they enter them in an online database and calls upon students who have demonstrated understanding, but who have not shared with the class recently, to explain the meanings of these roots and predict the meanings of the words “*endothermic*” and “*exothermic*”. After clarifying that endothermic means “absorbing heat”, while exothermic means “releasing heat”, Mr. S asks students to identify the hot and cold pack reactions as

Connections to the CA CCSSM: MP. 4
Connections to CA CCSS for ELA/Literacy: CA ELA 11-12.1.2
Connection to CA ELD Standards : ELD.P1.11-12.3, ELD.P2.11-12.6c
Connections to the CA EP&Cs: None

The NGSS in Action in Tandem with CA CCSS for ELA/Literacy and the CA ELD Standards

The vignette presents an example of how teaching and learning may look in a high school classroom when the CA NGSS are implemented in tandem with the CA CCSS for ELA/Literacy and the CA ELD Standards. The purpose is to illustrate how a teacher engages students in three-dimensional learning by providing them with experiences and opportunities to develop and use the Science and Engineering Practices and the Crosscutting Concepts to understand the Disciplinary Core Ideas associated with the topic in the instructional segment. An additional purpose is to provide examples of how language and literacy development are cultivated through interactive and engaging science literacy learning tasks. The vignette includes scaffolding approaches for English learner (EL) students. It is important to note that the vignette focuses on only a limited number of standards. It should not be viewed as showing all instruction necessary to prepare students to fully achieve NGSS performance expectations or complete the instructional segment. Neither does it indicate that the performance expectations should be taught one at a time.

The vignette uses specific themes, but it is not meant to imply that this is the only way in which students are able to achieve the indicated performance expectations and learning target. Rather, the vignette highlights examples of teaching practices, lesson organization, and possible students' responses. Science instruction should take into account that student understanding builds over time and is extended by revisiting topics and concepts throughout the course of the year. In addition, some topics or concepts require different pedagogical and scaffolding approaches, depending on individual student needs. Finally, while the vignette provides several illustrations of pedagogical practices, it does not include everything that educators need to consider when designing and facilitating learning tasks. All learning environments should follow research-based guidelines.

Vignette for High School:
Chemical Energetics

Background

Mr. S has noticed that his chemistry students often memorize diagrams and charts presented in the textbook, yet their appreciation and significant understanding of the complex phenomena such models represent could be stronger. The ability to develop and use models is emphasized as a science and engineering practice in NGSS, as well as a standard for mathematical practice in the Common Core State Standards for Mathematics (MP.4). In an effort to build the science and engineering practice of developing and using models, while addressing students' understanding that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy, Mr. S develops a two-day lesson as part of a larger instructional segment on chemical reactions to help students discover the power and limitations of models.

Mr. S is a chemistry teacher in an urban, multi-ethnic high school with a large percentage of English learners. Several of the students in his chemistry class speak a non-standard dialect of English at home. Ten of his students have been reclassified as fully English proficient within the last three years, while another five are at either the Expanding or early Bridging level of English proficiency. These students have a strong grasp of conversational English but need support understanding and using more academic language. Two of his students are newcomers and are at the early Emerging level of English language proficiency. Mr. S's goal is to provide an appropriate level of support for all of his students so each can not only learn science content deeply but also increase their ability to read and write complex scientific texts. Mr. S espouses the view that learning is an active, contextualized process of constructing knowledge, and he has designed this series of lessons to provide opportunities for his students to construct their own understanding through well-designed experiences and reflections.

Lesson Context

Mr. S begins preparing students to conduct investigations of *exothermic* and *endothermic* reactions and develop models by presenting the class with familiar objects that absorb or release heat.
He distributes reusable hot and cold packs, used to treat sports injuries, and instructs his students to flex the bags, feel the change in temperature, measure the temperature change using infrared thermometers obtained from the local building supply store, and record these changes in a collaborative online database. Despite variations in individual temperature readings, students will notice similar patterns in the temperature gains or losses for the hot and cold packs.

The following learning target and NGSS performance expectation guide teaching and learning for the lesson.

Learning Target: Students classify a variety of reactions as endothermic or exothermic, and represent each using two or more types of models.

CA NGSS Performance Expectation:

HS-PS1-4 – Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

Lesson Excerpts

Mr. S prepares a table in the collaborative online document so that students can work in small groups to interpret the meaning of the terms *endothermic* and *exothermic*. Each group must complete the table together, adding to what the other groups are entering in the database in real time. He has strategically paired students who have different levels of science knowledge and skills and proficiency in using scientific vocabulary. For instance, he pairs a student with high literacy in scientific texts with a student who has an avid interest in chemistry but is a struggling reader. Mr. S also pairs one of the newcomer EL students at the early Emerging level of English language proficiency with a former EL student who speaks the same native language. He then strategically joins these pairs into groups of four, making sure to monitor their interactions. He is attentive a ready to step in to mediate decision-making processes or to provide scaffolds, as needed, to ensure all students perform effectively.

Mr. S has written the words *endothermic* and *exothermic* at the top of the chart and asks students to

Standards the Vignette Addressed

CA NGSS Performance Expectation **HS-PS1-4** – Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Developing and Using Models ▪ Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS1-4), (HS-PS1-8) **Planning and Carrying Out Investigations** ▪ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS1-3) **Using Mathematics and Computational Thinking** ▪ Use mathematical representations of phenomena to support claims. (HS-PS1-7) **Constructing Explanations and Designing Solutions** ▪ Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS1-5) ▪ 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-PS1-2)	**PS1.A: Structure and Properties of Matter** ▪ Stable forms of matter are those in which the electric and magnetic field energy is minimized. A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-4) **PS1.B: Chemical Reactions** ▪ Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-4),(HS-PS1-5)	**Patterns** ▪ Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-1), (HS-PS1-2),(HS-PS1-3), (HS-PS1-5) **Energy and Matter** ▪ In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-8) ▪ The total amount of energy and matter in closed systems is conserved. (HS-PS1-7) ▪ 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-PS1-4) **Stability and Change** ▪ Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-6)

Connections to the CA CCSSM	
MP.4 – Mathematically proficient students are able to identify important quantities in a practical situation and map their relationships using such tools as diagrams, two-way tables, graphs, flowcharts and formulas.	
Connections to CA CCSS for ELA/Literacy	**Connections to CA ELD Standards (Expanding)**
RST.11-12.4 – Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*. **SL.11-12.5** – Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.	**ELD.PI.11-12.3** – Negotiate with and persuade others . . . in discussions and conversations using learned phrases . . . and open responses to express and defend nuanced opinions. **ELD.PI.11-12.6c** – Use knowledge of morphology (e.g., affixes, Greek and Latin roots), context, reference materials, and visual cues to determine the meaning of unknown and multiple-meaning words on familiar and new topics. **ELD.PII.11-12.1** – Apply analysis of the organizational structure of different text types . . . to comprehending texts and to writing increasingly clear and cohesive arguments, informative/ explanatory texts, and narratives.

Understanding Bulk Behavior at the Microscopic Level

Once students have added energetics to their **model** or **argument**, they can **construct** better **explanations** for how microscopic interactions account for bulk property behavior (*HS-PS1-3*). If students apply the concept of ***scale***, they can explore the complex concept of electrostatic forces. Students learn how to use the mathematical representation of Coulomb’s Law as part of the **evidence** for their **explanation** for understanding bonding (*HS-PS2-4* and *HS-PS3-5*). Students will also learn how the nucleus of one atom has enough attractive force to pull one, two, or three electrons away from nuclei that does not have the same attractive force on its own electrons. Finally, by applying the principles of electrostatic attraction, students should be able to predict that the resulting cations and anions will be attracted to each other and form ionic bonds. As to covalent bonding, students will learn that the differences in how these molecules dissolve, their boiling points, and the types of reactions they undergo is dictated by the bonds between atoms. In order to lower their respective ***energy***, two non-metal atoms come together. As they come very close to one another, the respective orbitals of the atoms overlap, trapping two electrons in the energy field, creating the covalent bond (*HS-PS3-5*). The differences in how these two bonds are created is often overlooked, resulting in oversimplified definitions. Getting to this level allows students to fully pursue the relationship between bulk effects and microscopic ***causes*** (*HS-PS1-3*).