# Using Basic Chemistry to Study Energy Resources

***Michael A. Doody***

## Rationale

I teach Chemistry at a public high school in New Castle, Delaware. We are transitioning from the Delaware State Science Standards to the newly developed Next Generation Science Standards (NGSS), which places an increased emphasis on experiential learning and the application of concepts to real-world scenarios while devaluing memorization of individual pieces of content. Students at our school choose a career pathway their freshman year, and must take at least three consecutive courses in that discipline in order to graduate on time. Career pathways include Air Force Junior ROTC, Culinary Arts, Architecture, Allied Heath, Science, Visual and Performing Arts, and many more. Our school is on an every-other day block schedule: I see my students for 90 minutes every other day for the duration of the school year. Students typically take between seven and eight courses a year depending on their career pathway and any elective courses.

Depending on a student's career pathway, Chemistry may or may not be a required course. For instance, students in the Science pathway are required to take Chemistry, while students in Visual and Performing Arts may just need a blanket three science credits. However, the guidance department encourages all college-bound students to take Chemistry their junior or senior year. Because of this, my students are predominately 11th and 12th graders with a wide range of aptitude and interest in science. Nearly 90% of all Chemistry students indicated in the beginning of the year survey that they plan to attend a four year college after graduation. The course guidelines at my school do not require that students take any type of environmental science course, so many students miss out on the opportunity to learn about the broad topic of energy.

The 2015-2016 school year was my first year teaching the Chemistry curriculum, and I often found the content was disconnected with NGSS and student interests. I also found that some of the content was repetitive with material taught in the Science I class students take as freshmen. Since I spent a good portion of the first marking period re-teaching Science I material, I was unable to explore additional topics that were of interest to my students at the end of the year. This year, my peer learning community (PLC) made the decision to cut out a lot of the repetitive material from the curriculum. This will leave the last two weeks of the school year open for the exploration of additional topics.

My goal is to use this unit during that two week period and as a portion of students' cumulative final exam. This unit will engage students in a basic survey of the various energy resources that power the United States. I think this unit will pique student interest much more than traditional cumulative exam questions and will better align with the NGSS performance expectations. In a teaching guide published by the American Chemical Society, it is recommended that chemistry curriculum include lessons on the conservation of matter and energy, behavior and properties of matter, the particulate nature of matter, and the concepts of equilibrium and driving forces.[1] Students will integrate their knowledge of each of these recommended concepts in this unit, as they study a specific form of energy used in the United States. Additionally, in the 2011 book *Energy Explained*, authors Vikram Janardhan and Bob Fesmire call for an increase in energy literacy. They wrote: "Modern society depends on abundant and reliable supplies of energy, and it is fundamental to virtually everything we take for granted in our daily lives. And yet, most of us know very little about it."[2] Throughout their book they appeal to a broad and less scientifically-inclined audience through colorful language, wondrous analogies, and silly figures and diagrams. The authors' initial statement echoes the sentiment expressed by the late, great Carl Sagan, who once famously said "We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology."[3] Having students apply their chemistry knowledge to something as simple, yet powerful, as the energy that powers their daily lives is about as realistic of problem-based learning unit as I can imagine.

## Background Content

### Energy and Power

Understanding the definitions of, and differences between the terms "energy" and "power" is a critical first step for students as they begin this unit. Energy is classically defined as "the capacity to do work" or "usable power." However, this definition needs to be broken down for students since most have yet to take a physics course. According to Nancy Carpenter, author of *Chemistry of Sustainable Energy*, the key word in this classical definition is capacity. She explains the definition in more friendly terms: "some amount of energy is required to carry out some task." Power, then, can be defined as the rate at which energy is generated or consumed.[4] Students will likely struggle with these abstract definitions and will need to be supported with concrete examples to develop the required understanding. More information on energy and power as they pertain to this unit can be found below in the subsection Content Delivered in Unit.

## Required Prior Knowledge

Because this unit is the last of the year and serves as a cumulative final exam, students will have covered the major chemistry topics set forth by the ACS as well as the NGSS. Such topics include the Law of Conservation of Mass, the First and Second Laws of Thermodynamics, the five major types of chemical reactions (synthesis, decomposition, single replacement, double replacement, and combustion), the difference between endothermic and exothermic reactions, the basics of how catalysts work, how to apply the Law of Conservation of Mass to balance chemical reactions, and stoichiometry. Students will have also had exposure to gas laws and acid/base chemistry at this point.

### *Law of Conservation of Mass and Thermodynamics*

Students will have learned about the French chemist Antoine Lavoisier and his remarkable contribution to the development of the Law of Conservation of Mass (LCM), which states that mass is never created nor destroyed in chemical reactions or physical transformations. Students will have applied this law many times over by completing closed-system experiments such as the reaction between baking soda and vinegar. The LCM is shown by the total mass of the system before the reaction equaling the total mass of the system after the reaction within error. Additionally, students will have applied the LCM by writing and balancing chemical equations.

The First and Second Laws of Thermodynamics are fundamentals of physics, but they are also taught in Chemistry as a mechanism for understanding the progression and outcomes of chemical reactions. As explained in *Fundamentals of Energy Production*, the First Law of Thermodynamics (1st LT) states that energy cannot be created or destroyed; it can only be changed from one form to another. This has been popularized as the saying "you can't win, you can only break even."[5] The Second Law of Thermodynamics (2nd LT) states that entropy always increases.[6] In other words, energy transformations mostly proceed unidirectionally from higher or more useful forms such as chemical energy to lower or less useful forms of energy such as heat energy. This law has also been popularized as the saying "not only can you not win the game, you can't even break even." Like the LCM, the 1st LT and 2nd LT are quite abstract and must be demonstrated and explained in a variety of ways and times in order for students to build deeper understanding and meaning. One way this is achieved is through a discussion of the internal combustion engine (ICE) and its efficiency. Since almost all students are familiar with the ICE through personal experience, it is a valuable and engaging teaching tool.

*Types of Chemical Reactions*

Students learn about five major types of chemical reactions in my class. These include synthesis, decomposition, single replacement, double replacement, and combustion. Below is a general description, generic equation, and specific example for each.
Synthesis: a reaction where two elements react to produce one entirely new substance.
Generic Equation: $A + B \rightarrow AB$
Specific Example: $2H_2 + O_2 \rightarrow 2H_2O$

- Decomposition: a reaction where a compound breaks down into its individual components.
    - Generic Equation: $AB \rightarrow A + B$
    - Specific Example: $2NH_3 \rightarrow 3H_2 + 2N_2$
- Single Replacement: a reaction in which an element replaces another element in a compound.
    - Generic Equation: $AB + C \rightarrow CB + A$
    - Specific Example: $2AgNO_3 + Cu \rightarrow Cu(NO_3)_2 + 2Ag$
- Double Replacement: a reaction in which elements from different compounds replace one another.
    - Generic Equation: $AB + CD \rightarrow CB + AD$
    - Specific Example: $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$
- Combustion: a reaction in which a hydrocarbon reacts with a stoichiometric amount of oxygen to produce carbon dioxide and water
    - Generic Equation: $C_nH_{2n+2} + O_2 \rightarrow CO_2 + H_2O$
    - Specific Example: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Students are introduced to this topic by comparing each of the reaction types to relationships. In this analogy, a synthesis reaction is compared to two people starting to date, a decomposition reaction is a breakup, a single replacement is a breakup followed by one person dating someone new, and a double replacement reaction is two breakups followed by switching partners. I do not have such an analogy for combustion, other than that it might be a relationship that blows up in both parties' faces. Students relate very well to this analogy and use it as they develop meaning. After the introduction, they then complete an NGSS-aligned laboratory investigation to identify the different reaction types based on observations.

*Balancing Chemical Reactions*

Since the concept on balancing chemical reactions is a fundamental outcome of the LCM, students are reminded of this concept before beginning this unit. Additionally, this unit fits very well with the types of reactions (discussed above). As students learn about the different types of reactions, they take time to practice balancing them. At this point in the year, they have enough background knowledge to observe a reaction, predict the products that are being formed (based on their understanding of periodicity and bonding), and write a chemical equation by using the generic forms as templates. In this unit, students learn how to satisfy the LCM in terms of chemical reactions by using coefficients and counting atoms. Students are taught to write out the equation and then identify the numbers of each atom present on each side of the equation. In cases where an element appears more than once on the same side of the equation, students are told to list out the numbers individually. An example is shown below:

Unbalanced form:

| $HCl$ | + | $Mg(OH)_2$ | → | $MgCl_2$ | + | $H_2O$ |
|---|---|---|---|---|---|---|
| 1 H | | 1 Mg | | 1 Mg | | 2 H |
| 1 Cl | | 2 O | | 2 Cl | | 1 O |
| | | 2 H | | | | |

Note how the hydrogen on the reactant side is split since it appears in two compounds. At this point students will begin using coefficients to attempt to balance the equation. The coefficients apply only to the element or compound they directly precede. Once the coefficients have been applied, students then list out the numbers again to ensure that the same number of each element appears on both sides of the equation.

Balanced form:

| $2HCl$ | + | $Mg(OH)_2$ | → | $MgCl_2$ | + | $2H_2O$ |
|---|---|---|---|---|---|---|
| 2 H | | 1 Mg | | 1 Mg | | 4 H |
| 2 Cl | | 2 O | | 2 Cl | | 2 O |
| | | 2 H | | | | |

The most challenging chemical reactions for students to balance are those with polyatomic ions (such as $OH^-$ in the example above) and combustion reactions. In my experience, there are two factors that contribute to students' difficulty in this area. Firstly, for hydrocarbon compounds with more than a few carbons, students may have to complete a series of steps such as doubling the hydrocarbon and rebalancing the entire equation. Second, the sheer number of atoms in these reactions can be daunting. An example of an "easy" combustion reaction and a "hard" combustion reaction are presented below.

Easy: Methane

| $CH_4$ | + | $O_2$ | → | $CO_2$ | + | $H_2O$ |
|---|---|---|---|---|---|---|
| 1 C | | 2 O | | 1 C | | 2 H |
| 4 H | | | | 2 O | | 1 O |

$$\begin{array}{ccccccccc}
CH_4 & + & 2O_2 & \rightarrow & CO_2 & + & 2H_2O \\
1\ C & & 4\ O & & 1\ C & & 4\ H \\
4\ H & & & & 2\ O & & 2\ O
\end{array}$$

Hard: Octane

$$\begin{array}{ccccccccc}
C_8H_{18} & + & O_2 & \rightarrow & CO_2 & + & H_2O \\
8\ C & & 2\ O & & 1\ C & & 2\ H \\
18\ H & & & & 2\ O & & 1\ O
\end{array}$$

$$\begin{array}{ccccccccc}
2C_8H_{18} & + & 25O_2 & \rightarrow & 16CO_2 & + & 18H_2O \\
16\ C & & 2\ O & & 16\ C & & 36\ H \\
36\ H & & & & 32\ O & & 18\ O
\end{array}$$

The trick with the “hard” reactions is to double the amount of hydrocarbon, as is seen above. Once this is done, the next step is to balance the carbon. Then the hydrogen can be addressed. In most cases, the coefficient applied to water (the only H-bearing compound on the product side of the reaction) is equal to the original number of hydrogen atoms on the reactant side. Because a large portion of this unit will focus on the combustion of hydrocarbons, considerable time will be spent on balancing these types of reactions.

### *Energy of Reactions and Catalysts*

In this unit students learn the difference between endothermic and exothermic reactions. Endothermic reactions are those that require the system consume energy and cause the surroundings to decrease in temperature. Exothermic reactions are those that release energy from the system and cause the surroundings to increase in temperature. Students learn that the nature of reactions is related to the amount of energy stored in the bonds of the reactants and the products they form when reacted. Specific examples of each type are given. For instance, the dissolution of ammonium chloride in water is an endothermic reaction, while the combustion of methane is highly exothermic.

Catalysts are introduced once students have mastered the above material. In previous classes, students have learned about enzymes and the lock and key mechanisms by which they operate. I use this as an introduction to the topic and go on to teach students that catalysts work to lower the activation energy of chemical reactions, allowing them to proceed with a smaller initial input of energy.

### *Stoichiometry*

Stoichiometry, simply explained, is the study of the relative amounts of substances involved in chemical reactions. While it is a difficult word to pronounce for students, once they complete enough practice problems, students often find it relatively easy (although time and space consuming) to complete stoichiometric calculations. In this unit, students learn to use balanced chemical reactions, amounts of one substance (in mass or numbers of atoms/molecules/compounds), and mole ratios to determine how much of another substance is present. Also discussed is the concept of limiting and excess reactants and percent yield. Stoichiometry is critical for success in this energy analysis unit because it will allow students to analyze reactions for efficiencies, cost-effectiveness, and their contribution to global climate change.

## Content Delivered in the Unit

Because most students have yet to take a physics or environmental science course, considerable time will be spent on delivering the background content necessary for the completion of the unit tasks to be discussed below. Additional material on the types of chemical reactions will be presented in this unit, with a focus on oxidation-reduction (REDOX) and electrolysis. Students will be presented with the definitions of energy and power, an overview of the major types of energy sources, basic organic chemistry, and the fundamental physics of electricity generation. Students will also have an opportunity to explore the economics, geography, and politics of energy in our society.

### *REDOX and Electrolysis*

In addition to the five major types of reactions presented above, students need to understand REDOX and electrolysis reactions in preparation for the energy analysis unit. REDOX reactions involve the transfer of electrons between two substances during a chemical reaction. This definition is based on the concept of oxidation numbers, which is equal to the number of electrons lost or gained by an atom of that element in a chemical process. Students will learn that elements are oxidized when their oxidation number increases (they lose electrons) and are reduced when their oxidation number decreases (they gain electrons). Students are taught this concept through the use of half reactions that include the electrons being transferred. An example is shown below for the reaction that may occur in a galvanic cell (i.e., a battery).

$$\mathrm{Zn} \quad + \quad \mathrm{Cu}^{2+} \quad \rightarrow \quad \mathrm{Cu} \quad + \quad \mathrm{Zn}^{2+}$$

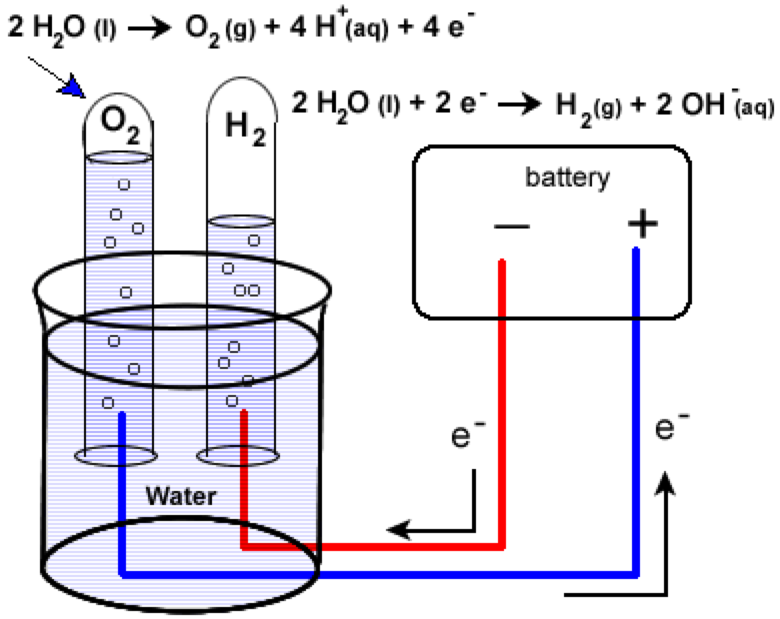
This equation can be broken down to trace the flow of electrons:

$$Zn \rightarrow Zn^{2+} + 2e^-$$
$$Cu^{2+} + 2e^- \rightarrow Cu$$

The two half reactions are then combined to show the balanced chemical equation. In this reaction, zinc metal is oxidized and copper ions are reduced. Therefore, copper is the oxidizing agent and zinc is the reducing agent. This is a challenging concept for students to learn because it requires a high degree of analytical thinking, but once students grasp the concept of the half reaction and connect the written equations with oxidation numbers from the periodic table, they will be set up for success in this unit.

Electrolysis is directly related to REDOX reactions and is defined as the process by which an electric current is passed through a substance to effect a chemical change. It just so happens that the chemical change occurs because the substances involved either lose or gain electrons. The process by which electrolysis occurs is modeled in the diagram below (Figure 1).

**Figure 1: Electrolysis of Water**[7]



These two types of chemical reactions are critical to the study of energy, as is presented below. REDOX can be applied to trace the flow the electrons in essentially all chemical reactions, and since electricity is simply the flow of electrons, understanding this reaction type will prove absolutely invaluable. Electrolysis is important as students learn about fuel cells and the generation of hydrogen fuel, as presented below.

### *Definitions and Types of Energy*

As presented above, the classical definition of energy is the capacity to do work. This differs from power, which is the rate of energy production/consumption/conversion/flow. Energy is typically measured in joules (J), but because of the magnitude of energy produced and consumed, higher order units of measure such as the kilojoule (kJ) or even megaJoule (MJ) are often encountered. Operationally, 1 J is the amount of energy required to apply a force of 1 Newton over a distance of 1 meter (m). In more understandable terms, 1 J is the amount of energy needed to lift a body of 102 grams (g) to a height of 1 m. It can also be defined as the amount of energy required to heat 1 mL of water by 1 $^{o}$C. Power is measured in watts (W). 1 W is equal to 1 J applied over 1 second, therefore a watt is equivalent to 1 J/s. Students may be familiar with the term "horsepower" or HP. 1 HP, which traditionally represented the amount of power of one horse or 7.5 men, is equal to 746 W. Other units that students may come across in this unit include the calorie (cal), which is a unit of energy equal to 4.18 J, the kilo-watt hour (kWh), which is a unit of energy equal to 3,600 kJ, and the British Thermal Unit (BTU), which is yet another unit of energy, and is equal to 252 cal and roughly 1055 J.[8]

There are several ways to classify the energy used in today's society. The first is through the ability of those energy sources to be replenished. Under this classification, there are two types of energy: renewable and nonrenewable. Renewable energy sources are defined as those produced from geophysical or biologically sources that are naturally replenished at the rate of extraction. Another way of defining renewable as that the energy source is replenished on human time scales. Examples of renewable energy sources include biomass, hydropower, wind energy, photovoltaic solar energy, high-temperature solar energy, low-temperature solar energy, geothermal energy, and ocean energy (in tides and waves). Nonrenewable energy sources are defined as those produced from sources that are not replenished on human-time scales. Examples of such sources include the petroleum sources such as oil, coal and natural gas, as well as nuclear power.

A different method for classifying the major energy types is through the use of the term "fossil fuels." Fossil fuels are those sources of energy that have been generated from the death and subsequent burial and "cooking" of ancient life forms such as plant matter (which gives rise to coal) and aquatic microorganisms (which gives rise to oil and natural gas). All other fuels are considered to be alternative fuels. It is important to note that most nonrenewable energy are fossil fuels, nuclear power is an exception to this rule. While the uranium (and maybe one day thorium) used in nuclear power plants is not a derivative of ancient life (excluding it from the fossil fuel category), it is a nonrenewable resource because it exists in finite quantities on Earth. The final classification of energy is as either primary or secondary. Primary energy sources are those raw materials with chemical, kinetic, or potential energy, and include everything from wind to oil to geothermal. Secondary energy is the widely useable form of energy we know as electricity, which has been termed the energy currency by many experts in the field.

Students will be challenged to research the chemistry of the following types of energy sources in this unit: coal, oil, natural gas, solar, hydrogen, nuclear, and biofuels. Wind energy is being left out because of a lack of basic chemistry principles. Each of these fuels will be discussed in some detail below.

The three fossil fuels (coal, oil, and natural gas) make up the vast majority of energy sources in the United States and the world as a whole. The energy stored in these fossil fuels has its origins in the sun. The story of the formation of coal starts some 250 to 290 million years ago during the Permian period when the earth was dominated by giant plant species. The plant species harvested solar energy and stored it as carbon compounds in their tissues. When some of the plants died, they were buried and did not decompose. This meant that the carbon stored in their tissue was not recycled into the ecosystem, but stored underground. Over time, more and more material built up over top of this dead plant material. As this occurred, temperature and pressure increased, essentially cooking the material. Eventually, this layer rich in organic matter lithified, creating what we now know as coal.[9] The formation of oil and natural gas deposits is a very similar story, except it takes place in the vast ancient oceans of the planet. As photosynthesizing organisms in upper portions of the oceans died, they sunk to the bottom. Some of this material was buried under sediment and exposed to high temperatures and pressures. Over millions of years, the high temperature and pressure cooked the material. Oil is the material that is less "cooked," while natural gas is the material that is more "cooked."[10] Students will engage in structured research in order to develop a more in-depth understanding of how fossil fuels are created and the chemistry that takes the energy stored in those fuels and converts it into electricity.

The term "solar power" is a broad one, and can applied to any number of specific energy capture technologies, including photovoltaics (PV), passive solar (or thermal solar), and solar thermoelectricity. In this unit, students will consider PV cells, which convert sunlight directly into electricity as well as concentrated solar thermal. A PV cell works by capturing incoming solar radiation or photons, which then displace free electrons in the cell's semiconducting material. As the electrons are displaced, the imbalance within the cell generates a difference in electric potential, which induces an electric current.[11] Concentrated solar thermal works by focusing sunlight via solar arrays onto a heliostat, which can be used to boil water and drive a turbine, or be used in conjunction with molten salt to store the energy for later use.[12] Student research will focus on the material science of the semiconducting materials used in PV cells and the properties of the molten salts used in concentrated solar thermal.

For this unit, the hydrogen power that students study will be that related to the splitting of water by electrolysis and fuel cells. Hydrogen can be generated in a variety of ways, but one of the simplest is through water electrolysis. In this process, water in an electrolyzer has a current passed through it. On the anode side of the electrolyzer, water is split into $H^+$, $O_2$, and electrons. The $H^+$ and electrons pass through a membrane to the cathode side where they react to form $H_2$ gas. The $H_2$ gas is then recovered for storage or use.[13] The $H_2$ can then be used in fuel cells to generate electricity. In a traditional hydrogen fuel cell, $H_2$ is fed to the anode and air is fed to the cathode. A catalyst located at the anode separates $H_2$ into $H^+$ and electrons, which take different paths to the cathode. The electrons travel through an external circuit, thus creating the flow of electricity, while the protons migrate to the cathode and react with oxygen to form water and heat as byproducts.[14]

Nuclear power is generated based on the chemistry and physics of nuclear fission. In the reactor core, uranium – and sometimes plutonium – is bombarded with neutrons. When the uranium is hit with the neutrons, it decays to generate heat energy and more neutrons. Those additional neutrons hit more uranium atoms, causing a chain reaction. The heat energy released by this process is used to generate steam, which is used to turn a turbine and generate electricity.[15] A simple nuclear reaction for uranium-235 is shown below.

$$^{235}U + n_o \rightarrow {}^{93}Rb + {}^{140}Cs + n_o + \text{heat}$$

Students will complete structured research on the nuclear chemistry involved in nuclear power. Students will also research radioactive decay chemistry in order to address one of nuclear power’s biggest downsides: the generation of large volumes of highly radioactive waste.

Biofuels follow the same basic chemistry as oil and natural gas. The biomass in some plant, say sugarcane, is refined or fermented to produce ethanol, which can they be used directly as a fuel[16]. The combustion of ethanol follows the chemical reaction shown below:

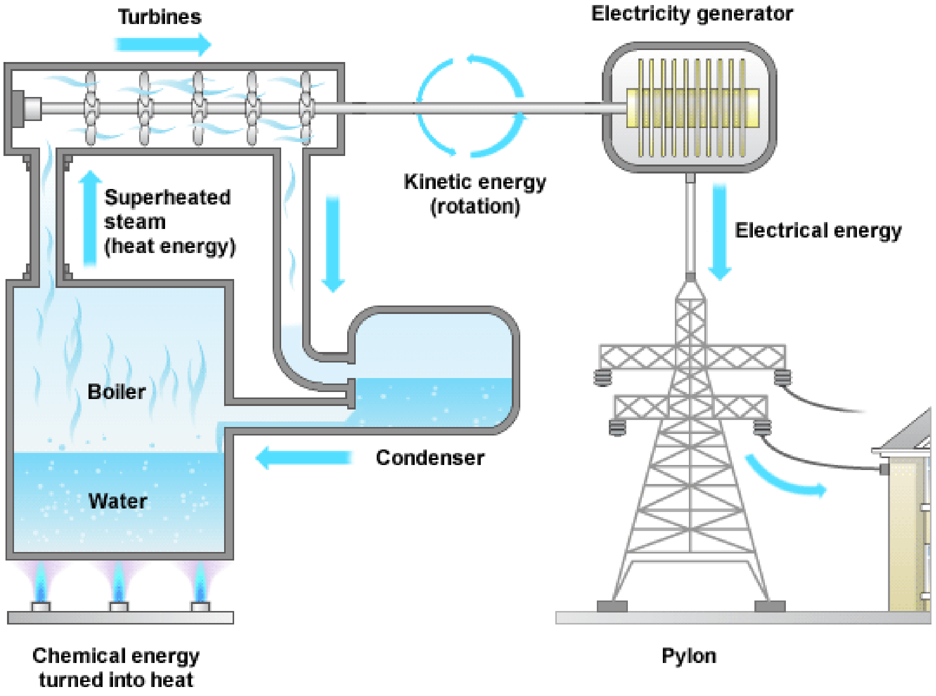
$$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

Students will complete structured research on biofuels to learn about the chemistry of the refining process and different types of biofuels.

### *Basic Chemistry of Energy and the Fundamental Physics of Electricity Generation*

The chemistry of energy sources like fossil fuels and biofuels is related to the energy stored in the bonds of those fuels. For example, the combustion of octane can only release the amount energy stored in the C-H and C-C bonds contained in that molecule (this is the 1st LT). Furthermore, we know that we cannot break even, since a great deal of energy from list reaction is not transformed to a usable form (this is the 2nd LT). For fossil fuels like coal, oil, and natural gas used in the generation of electricity, the story is much the same. Unlike the burning of octane for use in an internal combustion engine, the combustion of fuels for the purposes of electricity generation is done in order to generate steam from water, which then turns a turbine. The mechanical work done by the rotating turbine is then converted to electricity by a generator.[17] A basic diagram of this process is shown below.

**Figure 2: Generation of Electricity[18]**



Students studying any of these fossil fuels will conduct structured research into the exact chemistry of their fuel, as well as any refining necessary to prepare the fuel for use. Students assigned biofuels will research the different types of biofuels (corn, sugarcane, algae, synthetic biofuels, etc.). Nuclear power, though not a traditional fossil fuel, essentially works by the same principles. The heat energy released in the nuclear chain reactions is used to create steam, which turns a turbine. The resulting mechanical work is converted to electricity in a generator.[19]

Hydrogen fuel and solar power operate under completely different conditions. In the case of hydrogen fuels, the energy stored in the bond of the $H_2$ molecule can be harnessed through the use of fuel cells, as described above. The energy stored in the $H_2$ molecule is converted to electricity by recombining the $H_2$ with oxygen from air to form water.[20] In the case of PV cells, incoming photons induce an electric current in semiconductors.[21] Like with traditional fuels, concentrated solar thermal energy can be used boil water and drive a turbine, or it can be used in conjunction with a molten salt to store large amounts of heat energy, which can then later be used to boil water and turn a turbine.[22] Topics of research for students assigned these fuels include efficiencies, grid compatibility, and cost/political barriers.

## Strategies

Because this is a culminating project, in order for students to be successful, I will need to use certain teaching strategies throughout the year that focus on building comfortability with the NGSS Science and Engineering Practices: asking questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence, and obtaining, evaluating, and communicating information.[23] Most of my lessons involve two or more of these practices, but the one practice I will really need to focus on is communicating information, since students will be presenting to the entire class. My goal is to structure lessons in such a way that gives students plenty of practice throughout the year so that they are comfortable with presenting by the time the year ends.

One way I plan to do this is by using several jigsaw activities, where students must obtain information and then trade with others. This activity is a low-stakes way of getting students to communicate their findings with others and can build students' confidence in their ability to speak to others. Another way of helping students practice communicating information is through the use of a flipped classroom, where students engage in traditional educational activities such as reading and taking notes at home and then complete discussions, labs, or other interactive activities in the classroom.[24] By reducing the amount of time spent in class on traditional learning, students have more time to engage with one another and develop communication skills that will serve them both in this project and in life after high school.

Other practices that will be a focus of this unit include developing and using models, constructing explanations, and engaging in argument from evidence. Students will use models, including chemical equations and diagrams to present information on their specific energy source. Students will also need to piece together all of their research to construct an explanation for why certain energy sources are more economically feasible, why some are more environmentally friendly, and why some face legitimate obstacles given the political climate. These explanations will be critical as students begin to argue from evidence in favor of one energy source versus the others.

## Activities

### Basic Chemistry and Physics

Students will read an excerpt from our textbook to learn about REDOX and electrolysis, two fundamentals referenced above. A required outcome of this part of the unit is to correctly trace the flow of electrons in REDOX reactions. To that end students will be given several practice problems focused on building the skills necessary to balance REDOX reactions, identify the oxidizing and reducing agents, identify which substance was oxidized and which was reduced, and ultimately trace the flow of electrons from on substance to another. Another outcome of this part of the unit is to understand how electrolysis is simply one example of REDOX. To that end students will complete a basic experiment using pencils, a beaker of water, wires, and a 9-v bolt. By connecting the pencils to the battery and then submerging them in water, water will undergo electrolysis and students will observe the evolution of $H_2$ and $O_2$ gas.[25] Students can then write and balance a simple set of REDOX reactions and then combine them into a decomposition reaction to model this experiment.

In order to learn the fundamental vocabulary necessary to discuss energy sources, students will use a Quizlet app embedded in Schoology. In this app students can view digital flashcards to familiarize themselves with the terminology. To build recall, students can then quiz themselves (or other students) using a variety of engaging formats, including matching, spelling, and an arcade-like game where students have to type the term to match the definition before the definition falls from the top of the screen to the bottom of the screen. I have found that using Quizlet to build vocab is much more effective than traditional methods of reading and writing the term along with its definition in a notebook. I also notice that my lower level students are more engaged and less likely to get distracted or become frustrated.

The last piece of information needed before students are introduced to the many energy sources is the fundamental physics of electricity generation. Nearly all students will have studied electricity in middle school and built basic circuits, but only a few select students (depending on their career path) will have taken any high school courses that deal with the subject matter. Therefore I feel it is necessary to take the time to teach this concept instead of having students tackle it independently. Some of the terms involved in electricity generation will appear in the Quizlet app described above, so students will have some degree of background knowledge going in to this part of the lesson. To teach the fundamentals I will have students attempt to trace the electricity that comes into their homes back to some origin. It is my expectation that most will trace it to a wire and maybe to a power plant of some sort, but that many will skip the transformers, generators, and turbines. This will provide an avenue for me to introduce these, with an emphasis on turbines and generators. At this point in the lesson students will read a short document from GE and watch the accompanying video.[26] Students will then revise their original model of how electricity gets to their home.

## Introduction to the Major Energy Sources in the US

By viewing several videos in EdPuzzle supplemented with direct instruction, Students will be introduced to some of major types of energy sources in the U.S. by watching videos in EdPuzzle. EdPuzzle is a video learning tool that allows teachers to embed guiding questions in the video to maximize learning. These video will cover the following energy sources: coal, oil, natural gas, nuclear, biofuels, hydroelectric, wind, solar (photovoltaic and thermal), geothermal, and hydrogen. Special attention will be given to coal, oil, natural gas, solar, and hydrogen because of their alignment with the overall goals of the unit. Students will watch the following videos:

- “Fossil Fuels 101”[27]
- “Nuclear Reactor: Understanding How it Works”[28]
- “Biofuels 101”[29]
- “Energy 101: Hydropower”[30]
- “Wind Power”[31]
- “How Do Solar Panels Work?”[32]
- “How does GE’s Concentrated Solar Power Plant with Storage work?”[33]
- “Energy 101: Geothermal Energy”[34] and
- “Solar Hydrogen Fuel Cell and Electrolyser Demonstration.”[35]

Once students have watched the videos I will facilitate a discussion of the key points from each of the videos. These questions will be directly related to the questions embedded in EdPuzzle. Students will have an opportunity to ask questions about the content from the video and any other general questions they have about energy sources. Participation in this discussion will help me gauge student interest in the topic and project. It will also help me strategically group students based on interest in specific energy sources. Finally, I will summarize the key points in note form for students.

## Researching Energy Sources

Students will be strategically placed into groups and assigned an energy source to research. Groups will be structured based on a combination of factors including grades, potential group dynamic, and interest in specific energy sources. One way I have grouped students in the past is by ranking students according to grades and then pairing high achievers with average students, and average students with those who are struggling. This ensures a good mix of competencies and motivation. I will use a modified version of this while also factoring in group dynamics and special interest in specific energy sources.

Two class periods will be allotted for research. During this time students will have access to several pre-selected texts, articles, videos, and websites. A sample of these resources is provided below.

- All videos listed above
- United States Department of Energy website
- Chapters 4 and 5 of Smil's *Energy Density book* 36

In order to allow for academic freedom, students will be given the opportunity to do additional research in the computer lab. This will ensure that no two presentations across my four sections will be the same. Additionally, it will challenge students to find and separate high quality sources from the mass of information located on the internet.

In order to promote consistency, students will be required to complete a research graphic organizer. This document will have space for students to record information on the basic chemistry (chemical reaction(s) involved, stoichiometry, etc.), efficiency, climate impact, grid compatibility, and economic and political influences.

## Presentations and Opinion Paper

After compiling their research, students will present their findings on the energy source they were assigned. Students will be encouraged to use digital media such as PowerPoint, Prezi, Storyboard, etc., but traditional poster presentations will also be allowed. In their presentation, students will need to present some background on the energy source, including how long it has been in use and where the energy source comes from. The bulk of the presentation should focus on the basic chemistry of their energy source: what types of reaction(s) are involved? What does the stoichiometry look like? How efficient is the energy source in terms of converting the energy into electricity? Finally, students should discuss how compatible the energy source is with the current power grid and any economic or political incentives or barriers to the continued use of their energy source. While other groups are presenting, students in the audience will be filling out a note sheet or graphic organizer given to them by the presenting group. This ensures that students get the necessary information out of each presentation in a structured and reproducible manner.

After presentations have concluded, students will use their notes/graphic organizers to write a one-to-two page opinion paper on which *one* energy source should be most heavily invested in by the US in the next decades. Students will need to include a basic summary of the chemistry involved in the use of that particular source of energy and connect that chemistry to efficiency, potential climate impact, grid compatibility, and political and/or economic incentives or barriers. Combined with their presentations, this opinion paper will count as the students' final exam grade.

## Bibliography

American Chemical Society. *ACS Guidelines and Recommendations for the Teaching of High School Chemistry.* Washington, D.C.: ACS, 2012.

Association, New Mexico Solar Energy. *Electrolysis.* n.d. http://www.nmsea.org/Curriculum/7_12/electrolysis/electrolysis.htm (accessed 11 5, 2016).

British Broadcasting Company. *Generation of Electricity.* 2014. http://www.bbc.co.uk/bitesize/standard/physics/energy_matters/generation_of_electricity/revision/1/ (accessed 11 5, 2016).

Carpenter, Nancy. *Chemistry of Sustainable Energy.* Boca Raton, FL: CRC Press, 2014.
Curriculum, Saskatechewan Evergreen. *Redox Reactions & Electrochemistry.* June 2006. https://sites.prairiesouth.ca/legacy/chemistry/chem30/6_redox/redox3_3.htm (accessed December 18, 2016).

*Nuclear Reactor: Understanding How it Works.* Directed by ELearnin. 2013.

*Biofuels 101.* Directed by Student Energy. 2015.

*Fossil Fuels 101.* Directed by Student Energy. 2015.

Energy, United Stated Department of. *Fossil Energy.* February 12, 2013. http://www.fe.doe.gov/education/energylessons/coal/gen_howformed.html (accessed November 30, 2016).

Energy, United States Department of. *Biomass Technology Basics.* August 14, 2013. https://energy.gov/eere/energybasics/articles/biomass-technology-basics (accessed November 30, 2016).

—. *Concentrating Solar Power Basics.* August 20, 2013. https://energy.gov/eere/energybasics/articles/concentrating-solar-power-basics (accessed November 30, 2016).

*Energy 101: Geothermal Energy.* Directed by United States Department of Energy. 2014.

*Energy 101: Hydropower.* Directed by United States Department of Energy. 2013.
—. *Fuel Cells.* n.d. https://energy.gov/eere/fuelcells/fuel-cells (accessed November 30, 2016).

—. *Hydrogen Production: Electrolysis.* n.d. https://energy.gov/eere/fuelcells/hydrogen-production-electrolysis (accessed November 30, 2016).

—. *Solar Photovoltaic Technology Basics.* August 16, 2013. https://energy.gov/eere/energybasics/articles/solar-photovoltaic-technology-basics (accessed November 30, 2016).

*How does GE's Concentrated Solar Power Plant with Storage Work?* Performed by GE Renewable Energy. 2016.

General Electric. *Electricity 101.* 2016. https://powergen.gepower.com/resources/knowledge-base/electricity-101.html (accessed December 17, 2016).

Goldemberg, Jose. *Energy: What Everyone Needs to Know.* New York: Oxford University Press, 2012.

Harder, Edwin. *Fundamentals of Energy Production.* New York: Wiley, 1982.

*Solar Hydrogen Fuel Cell and Electrolyser Demonstration.* Directed by knowpub. Performed by Steven Harris and Roy McAlister. 2007.

Hertz, Mary Beth. "The Flipped Classroom: Pro and Con." *Edutopic.* December 22, 2015. https://www.edutopia.org/blog/flipped-classroom-pro-and-con-mary-beth-hertz (accessed December 16, 2016).

Janardhan, Vikram, and Bob Fesmire. *Energy Explained.* New York: Rowman & Littlefield, 2011.
*How Do Soalr Panels Work?* Directed by TED-Ed. Performed by Richard Komp. 2016.
*Wind Power.* Performed by NOVA PBS. 2012.

NRC. *Three Dimensional Learning.* n.d. http://www.nextgenscience.org/three-dimensions (accessed December 17, 2016).

Nuclear Energy Institute. *How Nuclear Reactors Work.* 2016. http://www.nei.org/Knowledge-Center/How-Nuclear-Reactors-Work (accessed November 30, 2016).

Sagan, Carl. *The Demon-Haunted World: Science as a Candle in the Dark.* New York: Random House, 1995.

In *Power Density: A Key to Understanding Energy Sources and Uses,* by Vaclav Smil. Cambridge, MA: MIT Press, 2015.

Tools, Home Science. *Splitting Water.* 2014. http://www.hometrainingtools.com/a/electrolysis-science-project (accessed December 17, 2016).

## Appendix A

In this unit I will be addressing all three dimensions of NGSS: Disciplinary Core Ideas, Science and Engineering Practices, and Cross Cutting Concepts. An overview of the dimensions addressed is presented in Table 1 below.

**Table 1: NGSS Breakdown**

| Item | Number/Name | Explanation |
|---|---|---|
| Disciplinary Core Ideas | *HS.PS1.A: Structure of Matter* | Electronic structure gives rise to chemical reactions |
| | *HS.PS1.B: Chemical Reactions* | Reactions are involve collisions, rearrangements, and energy changes |
| | *HS.PS1.C: Nuclear Processes* | Nuclear reactions involve release or absorption of energy |
| | *HS.PS3.A: Definitions of Energy* | Energy changes are related to chemical interactions |
| | *HS.PS3.B: Conservation of Energy* | Total energy in a system is conserved |
| | *HS.PS3.D: Energy in Chemical Processes and Everyday Life* | Energy is converted to less useful forms |
| | *HS.PS4.B: Electromagnetic Radiation* | EMR is both a wave and particle |
| Science and Engineering Practices | *Developing and Using Models* | Students will use chemical equations to model the reactions related to specific energy sources and schematic models of the different ways electricity can be generated |
| | *Using Mathematics and Computational Thinking* | Students will use principles of stoichiometry and the laws of thermodynamics to evaluate different energy sources for efficiency and climate change potential. |

| | | |
|---|---|---|
| | *Construction Explanations* | Students will construct explanations for why certain energy sources are in vogue and why others are not. |
| | *Engaging in Argument from Evidence* | Students will write a summative opinion paper arguing in favor of a single energy source using information gathered in the unit. |
| | *Obtaining, Evaluating, and Communicating Information* | Students will conduct guided and independent research, present that research to one another, and have a productive dialogue concerning the U.S. energy portfolio |
| Cross-Cutting Concepts | *Scale, Proportion and Quantity* | Students will use algebraic thinking to examine scientific data and predict the change of one variable on another |
| | *Cause and Effect and Systems and System Models* | Students will examine how changes in systems can have non-linear effects |
| | *Energy and Matter: Flows, Cycles, and Conservation* | Energy in closed systems is conserved; changes in energy can be described in terms of flows; energy drives cycling of matter within and between systems; nuclear processes conserve protons and neutrons, not numbers of atoms |
| | *Structure and Function* | Molecular structure gives rise to functions and properties of natural as well as designed objects/systems. |

Students will be addressing the following NGSS Performance Expectations through this unit:

**Table 2: NGSS Performance Expectations**

| Performance Expectation | Explanation |
|---|---|
| HS-PS1-4 | Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends on changes in total bond |
| HS-PS1-5 | Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of reacting particles on the rate at which a reaction occurs |
| HS-PS1-7 | Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction |
| HS-PS1-8 | Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the process of fission, fusion, and radioactive decay |
| HS-PS3-2 | Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles and energy associated with the relative positions of particles |

---

[1] (American Chemical Society 2012)
[2] (Janardhan and Fesmire 2011)
[3] (Sagan 1995)
[4] (Carpenter 2014)
[5] (Harder 1982)
[6] (Harder 1982)
[7] (Curriculum 2006)
[8] (Goldemberg 2012)
[9] (U. S. Energy 2013)
[10] (U. S. Energy 2013)
[11] (U. S. Energy, Solar Photovoltaic Technology Basics 2013)
[12] (U. S. Energy, Concentrating Solar Power Basics 2013)
[13] (U. S. Energy, Hydrogen Production: Electrolysis n.d.)
[14] (U. S. Energy, Fuel Cells n.d.)
[15] (Nuclear Energy Institute 2016)

---

[16] (U. S. Energy, Biomass Technology Basics 2013)
[17] (British Broadcasting Company 2014)
[18] (British Broadcasting Company 2014)
[19] (Nuclear Energy Institute 2016)
[20] (U. S. Energy, Fuel Cells n.d.)
[21] (U. S. Energy, Solar Photovoltaic Technology Basics 2013)
[22] (U. S. Energy, Concentrating Solar Power Basics 2013)
[23] (NRC n.d.)
[24] (Hertz 2015)
[25] (Tools 2014)
[26] (General Electric 2016)
[27] (S. Energy, Fossil Fuels 101 2015)
[28] (ELearnin 2013)
[29] (S. Energy, Biofuels 101 2015)
[30] (U. S. Energy, Energy 101: Hydropower 2013)
[31] (NOVA PBS 2012)
[32] (Komp 2016)
[33] (GE Renewable Energy 2016)
[34] (U. S. Energy, Energy 101: Geothermal Energy 2014)
[35] (Harris and McAlister 2007)
[36] (Smil 2015)