How do we Power our Planet in the 21st Century

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Objectives

Humanity owes it fortunes to its ability to harness energy and generate power. Beginning with human ancestors using fire approximately one million years ago,[1] the control of fire may forever be humanity's most important cultural advancement. Controlling fire allowed us to generate heat and light; it afforded our ancestors protection from predators, allowed expansion of human activity to colder geographic regions and darker periods of night, and helped increase caloric intake. And yet, despite the fact that energy and power are integral to our daily lives, students harbor many misconceptions regarding energy. Moreover, in Delaware's public school science education pathway, students do not have the opportunity to learn about our energy supply, conservation and generation.

Much of what students will learn in their science classes is being modified. The state of Delaware and many other states across the country have adopted the Next Generation Science Standards. Districts and the state of Delaware have been working to discern and implement the standards for the last three years. The standards are more than just a set of facts or principles that students must memorize; they are presented as three woven dimensions of learning. These dimensions are the disciplinary core ideas (the content students should learn), the cross cutting concepts (the principles that connect across the disciplines of science, such as cause and effect), and science and engineering practices (what scientists do to investigate the natural world)[2] See appendix for list of practices, cross cutting concepts and standards addressed.

These standards will certainly raise the bar for the students at my school, in which 14% of students are special education, 5.5% English language learners, and just 4.7% meet the State's college ready benchmark as scored by the SAT. However, due to our exemplary career area and technical education, as well as many other factors, US News and World Report has awarded Delcastle a bronze medal.

These statistics do a nice job capturing the student population at my school; the student body performs a bit below the state average, but they work hard and leave high school with a valuable real world education focused on trades and jobs skill. What these performance statistics don't capture is another type of diversity in my school. Students from across the county attend our school, so depending on which school district students attended prior to high school, and also which career area my students work in, there can be a lot of diversity (socio-economic, academic, and cultural) in the classroom.

My school is working on adopting the Next Generation Science Standards. We are shifting our curriculum and focusing on explicitly teaching the scientific practices and cross cutting concepts such as analyzing and interpreting data, engaging in argument from evidence, and system models. These ideas will be reflected in my curriculum unit, which will be written for an eleventh grade Integrated Science class at a vocational high school. This unit addresses a major gap in our current curriculum.

The students at my school also have a gap in understanding in regards to their energy usage and generation. Traditionally, when this material is taught, we cover the differences between renewable and nonrenewable energy sources, what these sources are, and how they are harvested. This instruction doesn't go into much depth, but, even at this superficial level, students seem to have a lack of understanding of the application and practicality of the various energies sources like coal, oil, and gas. They've heard of the concept of the greenhouse effect and climate change in the news and know its politics but hardly know the science behind it.

Standards Addressed

The unit will begin by looking at data, historic and current, to learn how historic climate data is collected and look at current climate data to forecast the impact of climate change (standard HS-ESS3-5). We will look at sea level rise, temperature increase, and risk of extreme weather. This information will give us the foundation for our unit and set up the problem that needs to be addressed which is how do we sustainably meet our society's energy needs. Students will then investigate why CO_2 levels are causing these temperature changes.

Next, students will look at our current fossil fuels and extraction methods and evaluate which of our current fossil fuel technologies should be prioritized by the United States. Students will take the role of a policy maker that can control tax incentives. They will need to determine which company and technology should receive the tax incentives for their energy proposal. They will investigate the cost-benefit ratio for the extraction and usage of coal and coal fired power plants, deep sea oil drilling and refinement, or hydraulic fracturing of rocks for natural gas and its refinement. After the unit concludes our curriculum covers alternative energy options and other sustainable options to mitigate human's impact on the environment.

Background

Energy is essential to the survival of all life on Earth. We need energy to fuel the thousands of chemical reactions collectively known as our metabolism. The energy to drive our life processes comes from the food that we eat. If we trace back the energy in our diet through the food chain, it ultimately comes from the sun. In addition to the energy requirements of our diet, modern humans in developed societies also have energy demands for our homes, the generation of our material goods, and transportation.

But what is energy? It is all around us and in the news about calories and politics and international security. It is also a concept that my students struggle with and harbor many misconceptions towards. Students mix up the distinction between matter and energy and students don't know where their energy comes from.

By definition energy itself is abstract, except for light, energy is not a thing, it is a condition or state of a thing. Energy is the ability to do work. Energy can be stored as various forms of potential energy or energy can be manifest through motion or as kinetic energy. There are various forms of energy, such as heat (thermal), light (radiant), motion (kinetic), electrical, chemical, nuclear, potential, and gravitational.

For example, when I shoot a basketball, I am taking chemical energy stored in my body, captured from the food that I metabolized, converting it to kinetic energy of motion for my arms and transferring this to kinetic energy of the basketball. Some of this kinetic energy is converted to gravitational potential energy as the ball sails into the air and then is reconverted to kinetic energy as the shot falls. Some of the kinetic energy of the ball is transformed to sound energy as I hear the swoosh of the net. And to a minor degree, some of the kinetic energy of the ball traveling through the air is transferred to heat energy as friction from the gas molecules in the air slows the ball in flight.

This example illustrates the complexity of the energies involved in just a superficial look at a simple basketball shot. This example didn't explore the energy stored in the molecules within the basketball, the energy that it took to form the rubber in rubber trees or to process, produce, and ship the basketball. Nor was the elastic energy transformed and transferred as the basketball is dribbled and bounced described. Neither did this illustration attempt to elaborate energy pathways involved in the shooter's digestion and metabolism of his pregame snack.

Energy cannot be created nor destroyed and can only be transferred from one body to another or converted from one kind of energy into another. Energy is measured in a variety of units, but the SI unit is a joule (J), which is defined as the quantity of energy transferred to an object when the force of one newton acts on the object for a distance of one meter. A calorie is a unit of energy that students are familiar with in name, although they are surprised to learn that a calorie is a unit of energy. One calorie is the energy that it takes to heat up one kilogram of water by one degree Celsius. Another common unit of energy when investigating electricity is a British Thermal Unit (BTU) which is defined as the amount of work needed to raise one pound of water one degree Fahrenheit.

Power is connected to energy, but it measures the rate at which energy is transferred. The SI unit for power is the watt (W), which is defined as transferring one joule (energy) per second (time).

Both units for energy and power are augmented with prefixes to magnify or diminish these units. When you are talking about global energy consumption versus the output of a single photovoltaic cell you are going to be addressing vastly different scales. The common prefixes and their magnitudes are defined within the appendix.

History

The history of human energy usage and power generation beyond just the dietary calories required to sustain life, begins with our mastery of fire. The earliest evidence of human control of fire dates back to at least 400,000 years BC. Humans would burn wood and other forms of biomass to generate light at night, generate heat, and cook food.

Cooking food unlocked massive advantages for our human ancestors. First of all, our bodies can more readily digest cooked food. For example for the same amount of calories ingested, our body gets about 30 percent more energy from cooked wheat, oat, or potato starch. Cooking will soften the cell walls of plant material and will break down collagen in meat. Cooking also reduced the time that our ancestors had to spend doing things like chewing. Cooking also expanded our diets and allowed us to eat food that has a reduced risk of carrying pathogens such as salmonella.[3]

As history progressed, our ancestors discovered that the energy generated from burning wood and other biomass could be used to do a variety of other tasks that helped to further the development of human society. The heat from fire would later to be used to create things such as pottery and to refine metals from ore.

The problem with wood is that it takes quite a long time to generate forests, and it does not have the greatest energy density; compare the 16 MJ/kg of wood with the 24 MJ/kg for coal and the 55 MJ/kg for natural gas.[4] A clear-cut forest may take between 50 to 100 years to regenerate and large portions of the Earth are not a suitable environment generate wood biomass.[5]

As human history progressed, energy was harnessed not just from the burning of biomass, but from a variety of other sources. Wind for ships and mills, and gravitational potential energy of water to power mills and transport people or goods downstream.

Regardless, the main production of energy for human societies relies on the combustion of carbon containing compounds. From the earliest fuel of wood, followed by coal, oil, natural gas, and biofuels, each of these fuels or methods for energy generation rely on combustion reactions. Together, oil, coal, and natural gas accounted for more than

81 percent of the global energy supply in 2013, a number that has hovered around 80% since the 1990s.[6]

Combustion Reactions

Efficient combustion reactions always require molecular oxygen, O_2. Whenever something burns you are witnessing a combustion reaction. These reactions are exothermic, meaning that they release heat and energy. When organic molecules such as those in wood or natural gas combust completely with O_2, they produce the products water and carbon dioxide.

$$C_xH_x + O_2 \rightarrow CO_2 + H_2O$$

For example the balanced chemical reaction for natural gas, methane (CH_4) and ethanol (C_2H_6O) are demonstrated below

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
$$C_2H_6O + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

Regardless of the organic fuel used in a combustion reaction, there will be carbon dioxide produced. As the human demand for energy increases and fossil fuels are continuing to be used for energy production, there will be an ever-increasing amount of carbon dioxide introduced into our atmosphere.

Fossil Fuels

The big three fossil fuels used are coal, oil, and natural gas. This unit will have students learn about the tradeoffs of each of these fossil fuels and develop a plan as if they were politicians in change of prioritizing investment into the exploration of these fuels.

Fossil fuels are all formed by subjecting accumulated biomass (which first captured its energy from the sun) to immense quantities of pressure and heat over millions to hundreds of millions of years. It could be said that modern civilization relies unsustainably on the harvesting of ancient solar energy that cannot be replaced on the timescale of our civilization.

Coal

Coal is referred to as our first fossil fuel. Coals are sedimentary rocks that originated as plant material deposited in swampy environments, partially decomposed, and then subjected to high temperatures and pressures for up to 350 million years. Coal use has been observed in civilizations as far back as 2000 years ago with the Han dynasty in China. As coal is a rock, it is harvested and collected through mining operations.

There is a wide variety in types of coal, which is mainly determined by the duration of time the biomass has been heated and pressurized. Black anthracites, the coals that have been subjected to the longest period of time baking under Earth’s surface, have the greatest percentage of carbon in them. They date back to biomass that is 354-290 million years old. The next tier of coal is called bituminous coal and it has more oxygen and less carbon in it because it hasn’t been heated and pressurized as long. Bituminous coal has a carbon content between 82-91%. The newer coals, formed around 65 million years ago are referred to as lignites and they have a carbon percent in the 70’s. There are a variety of classifications of coal within and between the three broad categories. Coal and its associated products have a variety of other uses including metal-producing, metal working, cement industry, chemical industry, and the paper industry.[7]

The percent of U.S. energy generated from coal has been on the decline since the 1990s however the global use of coal continues to trend upwards until 2015. Much of the global rise in coal usage has been driven by developing economies in countries such as China and India, although China’s coal use dropped from 2014-2015.[8]

Harvesting Coal

Coal is essentially rock that needs to be mined out of the Earth. Mines need to be dug and coal needs to be extracted. The oldest method of mining is underground mining. In underground mining, a tunnel is dug and then extended through the coal bed. There is also the practice of open-pit or strip mining for coal. This method is highly efficient and able to recover most all of the coal, it is limited to areas where there is only a thin, 50-100 thick rock cover over the coal seam. While this practice is limited to certain geographic regions, it is greatly disruptive to the area because essentially the whole surface has been removed and dislodged to access the coal.[9]

Environmental Implications of Coal Use

Coal contains about two percent sulfur, which can from hazardous sulfur dioxide when burnt. Sulfur oxides are very reactive and are contributors to acid rain. Coal also generates more carbon dioxide per unit energy than any of the other fossil fuels. Acid may also drain from coal-mining operations, which has caused widespread pollution of streams and loss of fish and wildlife. Additionally, mining disrupts groundwater, causes soil erosion, and surface mining can convert acres of land to barren pits of dirt. According to the Department of Conservation and Natural Resources of Pennsylvania, mining-related environmental problems are expected to persist into the future.[10]

Coal also has a long history of impacting human health. Through the collapse or explosions of coal mines many coal workers have lost their lives. Historically some coal miners have also developed a condition called “black lung” after years of inhaling coal dust. Coal workers have a long history of sometimes violent and deadly attempts at unionizing. However through these hazardous conditions, a sense of pride and dignity is noted to reside with some coal workers, their families, and within their communities.[11]

Crude Oil

Oil, like coal, has been known since antiquity. There are locations throughout the world where oil seeps from the ground. Edwin Drake in Pennsylvania first developed oil as an economic entity in 1859. Oil is a liquid mix of hydrocarbons. Crude oil has a much higher energy density by mass than does coal. Oil can vary between practically no sulfur content to as high as three percent sulfur content, although a sulfur content of about one percent is most typical. Oil is incredibly important economically due to its use as the base ingredient in the production of gasoline, diesel, and plastic, vinyl, and other synthetic materials.

Petroleum or crude oil needs to be refined after it is pumped from underground. Petroleum is a mix of hydrogen and carbon containing compounds called hydrocarbons that may also contain elements such as sulfur, nitrogen, oxygen, and some metals. Refineries separate the crude oil mixture by heating the crude oil and using a distillery tower to let the different hydrocarbons condense at different temperatures. This helps separate the hydrocarbons based on the chemistry that those with the highest boiling points condense first at higher temperatures and those with lower boiling points condense further up the distillation tower at cooler temperatures. Various chemicals or modifications in temperature and pressure may be applied during this process to help make the contaminants easier to extract or to stabilize end products or ‘cracking’ longer hydrocarbon chains to produce more gasoline.[12]

Harvesting Oil

Unlike coal, oil is a liquid, which greatly affects the methods used to extract it from the ground. Oil is harvested from reservoirs underground. Variables such as the porosity and the permeability of the rock layer within which the oil resides are important to consider when planning for the extraction of a particular oil deposit. Wells are drilled with a drill bit and filled with a pipe to allow the oil to be piped out. Technologies have been developed to access oil not just from land but also offshore. To do this a floating rig is anchored above a well and piping connects the rig to the well under water. The EIA estimates there are 15 billion barrels of oil in the Gulf of Mexico compared to an estimated 29 billion onshore in the US. Offshore rigs are currently drilling in depths of up to 12,000 feet but rigs have been rated to be able to drill at a depth of up to 50,000 feet depending on the type of oil rig.[13] After the oil is extracted there are pipelines that ship the oil to land for processing and shipment. Before leaving office, President Obama announced a ban in offshore oil drilling in the Arctic through 2022, blocked expansion in the Atlantic and Pacific oceans while allowing some new leasing in the Gulf of Mexico.[14]

Environmental Implications of Oil Extraction

There are issues of oil spills and leaks that can have serious economic and environmental consequences. The worst oil spill in U.S. history started on April 20, 2010 with the explosion of the Deepwater Horizon oil rig operated by BP in the Gulf of Mexico, which killed 11 people. Due to the challenging conditions, such as its 5,000-foot depth and frigid water conditions, it took 87 days until the leak could be stopped. During that time an estimated 3.19 million barrels of oil leaked into the Gulf waters, much of which could have been watched from a live video stream. As much as 20% of the spill may have ended up on top of the seafloor due to the use of chemical dispersants which were used to break up the oil, allowing it to mix with seawater.

The oil spill was cleaned by containing a floating oil slick with buoys. The oil may then be physically removed, sorbents may be added to absorb oil, dispersants may also be added to break the oil into smaller pieces. 1.4 million gallons of chemical dispersants were used on the Deepwater Horizon oil spill, sprayed from the air and even directly injected into the wellhead. Although scientists believe injection into the well head did not have much of an effect and some dispersants actually exacerbated negative environmental impacts of the oil spill.[15]

The impact on wildlife was significant with an increase of dolphin deaths from 63 to an average of 200 per year. Sea bird losses were estimated to number in the hundreds of thousands. Shrimp fisheries were closed for most of the year. Slow-growing deep water corals suffered tissue damage and showed signs of lower survival rates. There are signs of wildlife with deformities after the spill. Over 1,000 miles of shoreline on the Gulf of Mexico was impacted and had to be cleaned and subsequent erosion rates in the areas cleaned have accelerated.[16]

Natural Gas

Natural gas like oil and coal has been used culturally for centuries. First documented around 1000 BC in Ancient Greece, natural gas has become an increasingly important fossil fuel in the United States. Coal has been the dominant fuel for electricity production in the United States for years, however it is forecasted that 2016 will be the first year that natural gas will surpass coal. Natural gas releases the least carbon dioxide per unit energy produced of all the fossil fuels.

The United States has been dependent on imported petroleum for more than half of our daily needs for many years. However, advances in technology and engineering such as horizontal drilling and hydraulic fracturing have allowed the United States to achiever a greater sense of energy independence.[17]

Harvesting Natural Gas

Natural gas harvesting occurs in many locations across the United States with a variety of drilling and extraction methods used depending on the nature of the deposits. The United States is undergoing an energy boom with the recent development of technology to access natural gas such as horizontal drilling. Horizontal drilling involves drilling a vertical well and then turning and drilling horizontally or parallel to the rock layer, typically a type of shale containing the natural gas. After the hole is drilled 5,000 to 9,000 feet deep and then drilled up to 10,000 feet horizontally, it is lined so that products and natural gas doesn't escape the well. While the process of horizontal drilling is a relatively recent advent, fracking was first commercially done in 1949.[18] Next the shale is hydraulically fractured by sending fracking fluid down at high pressure to create cracks in the shale rocks. The natural gas is allowed to escape or is pumped up from the well. Additional chemicals may be used to help liberate the natural gas from the rock layers.

Environmental Implications of Natural Gas

A major hazard of natural gas exploration revolves around water. First is the concern of the seepage of methane or fracking chemicals into water wells and drinking water systems. Methane is odorless and a homeowner may not notice the gas filling up and one spark can cause an explosion. There is no federal or state drinking water standard for methane and there is little research on the heath effects of methane. There is also risk with exposure the chemicals used in fracking fluid. Many of these are not disclosed to the public and some are known carcinogens or may cause neurological problems[19].

Gas extraction areas have been demonstrated to have an increased concentration of methane in drinking-water wells as opposed to drinking-water wells around similar geologic areas where there is no fracking taking place. The concentration of methane was also demonstrated to increase with increased proximity to the gas well.[20]

In the United States, hydraulic fracturing is relatively poorly regulated at the federal level compared to other forms of fossil-fuel extraction. The fracking wells are not covered under the Safe Drinking Water Act due to an exemption passed in 2005 and fracking wastes are not regulated as hazardous waste under the Resource Conservation and Recovery Act. 90 percent of United States natural gas wells are also not covered under the Clean Water or Clean Air Act. The Environmental Protection Agency has just recently asked firms to report a list of the chemicals used in fracturing fluids, and this reporting is only voluntary. Data is also not consistently collected or publicly available prior to drilling to determine a baseline of groundwater quality.

A second concern regarding water and fracking is the water used for the actual fracturing. Based on figures from 2011, Pennsylvania has used about 20 million gallons of water per day for fracking. This water then must be treated to remove the chemicals from fracking or simply stored away.

Methane may also seep from the wells and reports show it has been leaking from wells at a rate more than twice what the industry has reported and methane can trap much more heat as a greenhouse gas than carbon dioxide.

The withdrawal of oil and gas and injection of fluids underground are capable of inducing earthquakes. Earthquakes with a magnitude below 2 are routinely produced as part of the fracking process to access oil and gas. Several of the largest earthquakes in the U.S. midcontinent in 2012 and 2011 may have been triggered by nearby disposal wells. Researchers have noted that injection-induced earthquakes contribute to the seismic hazard and while only a small fraction of wastewater disposal wells appear problematic, earthquakes can result in property destruction, injury, and even death.[21]

Fossil Fuel Emissions and Climate Change

The formula to investigate the introduction of carbon dioxide emissions into the atmosphere is affected by a few key variables. The total carbon dioxide emissions are the product of P (population), S (the services consumed per person), E (the energy to supply these services), and C (the amount of carbon emitted per unit of energy).

$$P \times S \times E \times C = CO_2$$

The challenge with the reduction of carbon dioxide emissions is that most of the variables in the above formula that affect carbon dioxide emissions are increasing. Population growing an annual rate of 1.2%, the services required by the world’s growing population and developing nations are going up by a factor of 2 per year and the energy to supply the services demanding by the world’s growing population is going up at the very least by 0.6 per year. The challenge is then to reduce the amount of carbon dioxide generated by supplying the world’s population with energy. Therefore, the only way to reduce or eliminate carbon dioxide emissions is to drop C the amount of carbon emitted per unit of energy eventually down to zero.[22]

The reason why carbon is so important is twofold. The first reason is that carbon dioxide is a greenhouse gas and the second reason is that, once emitted, carbon dioxide stays in the atmosphere for a long time.

Carbon dioxide, along with water vapor, methane, nitrous oxide, fluorinated gases, and other gases are collectively referred to as greenhouse gasses. They have earned this name due to their ability to trap heat in the atmosphere. Of these gases, carbon dioxide made up 81% of the United State's green house gas emissions in 2014, followed by methane, and nitrous oxide.[23]

The correlation between green house gas concentration and global temperatures has been demonstrated through evidence that spans 670,000 years. Ice cores drilled in Antarctica give us data to reconstruct the global concentrations of carbon dioxide and methane and the temperature over Antarctica. These data show a correlation between the concentrations of green house gases and temperature. These data also show that the concentration of carbon dioxide has been between 200 and 300 parts per million volume (ppmv) over this course of time. Current carbon dioxide levels are about 400 ppmv and continuing to grow at a rate of about 2 ppmv/year[24].

Carbon dioxide is naturally present in the Earth's atmosphere as part of a global carbon cycle. However, humans are largely affecting the atmosphere's carbon dioxide content by introducing more carbon dioxide through our increased combustion of fossil fuels, and to a significantly lesser extent, by reducing the ability of forests and other photosynthetic carbon sinks to remove carbon from the atmosphere.

The problem is that once CO_2 is released into the atmosphere, there is no natural mechanism for the remediation of carbon dioxide. CO_2 tends to remain as such and not react with other compounds in the atmosphere. There are not chemical processes within the atmosphere that result in the degradation of carbon dioxide to any appreciable degree.

Carbon dioxide's lifetime is poorly defined because the gas is not destroyed, but it migrates between parts of the land-ocean-atmosphere system. Following a concentration gradient, some carbon dioxide diffuses into the ocean surface, but it takes between 400 and several thousand years for CO_2 to mix and dissolve to the deep ocean. The time that it takes for 600 – 500 ppmv of carbon dioxide to decay back to 300 ppmv is estimated to be as great as 5,000 years or as little as 500 years, assuming CO2 emissions have stopped[25]. Therefore, the carbon dioxide we produced over the next four decades will last for a timescale comparable to that of modern human history.

Carbon dioxide can be sequestered from the atmosphere by dissolving into the ocean water or by autotrophs that perform photosynthesis following the chemical reaction

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

The effects of the increased carbon dioxide concentration are quite concerning. One effect of increased carbon dioxide concentration is the melting of ice packs and permafrost. Observations of Greenland's costal areas from 2003 to 2005 by NASA's Gravity Recovery and Climate Experiment (GRACE) satellites show that Greenland has lost 155 gigatons of ice per year during that time. The loss of ice that occurred over those two years is equivalent to the amount of water that flows through the Colorado River over 12 years. According to Costal tidal gauge records, sea levels have risen about 200 mm since 1870. Sea level has varied over the course of Earth's history, but have had little change from 1AD to 1800AD. The 19th century saw sea levels begin to rise again and the 20th century saw an acceleration of the sea level rises. Sea levels have risen about 3 mm/year since the 1990s.[26]

As the permafrost melts there will be a rise in sea levels. According to NASA, sea levels are projected to rise between one and four feet by 2100. The sea level rise will be coupled with storm surges and high tides to further impact flooding along coastlines. Oceans take a long time to respond to warmer surface level temperatures due to water's high specific heat, or the quantity of heat needed to raise the temperature of a substance, so sea levels will continue to rise after 2100.[27]

Not only does the melting of permafrost lead to sea level rise, it can also lead to an acceleration of climate change. As this ice melts, it releases gases trapped within it including releasing even more carbon dioxide and methane. It also reveals areas of soil making them accessible for microbes and decomposition which will further increase carbon dioxide emissions. Evidence shows that this may cause the greenhouse gas levels go up by a factor of 10. As the ice caps melt, the land areas will darken reducing the areas albedo, the reflection of solar radiation. As the lands darken more solar energy will be absorbed and less will be reflected back into the atmosphere, which will further lead to an increase in temperatures. So an initial warming leads to more emission and more emission leads to more warming making a positive feedback loop.[28]

There will be changes in precipitation patters. There will be a trend towards increased heavy precipitation and increased droughts. The weather patterns will tend to get more extreme across the United States. There will also be an increase in droughts and heat waves. Hurricanes are also projected to become stronger and intense.[29]

There are a number of alternative sources for energy production that do not generate carbon dioxide emissions. After this unit concludes students will move on to the next unit in the integrated science course and learn about these energy generation techniques as well as their pros and cons and the geographic limitations posed by some of the alternative energy generations.

In summation, there are a variety of data points that supply evidence and warn of the risks posed by climate change. Climate change has been affected by the human activities of burning fossil fuels. We will need to shift towards carbon neutral energy generation techniques to reduce carbon dioxide emissions and we will need to begin developing technologies to address the current carbon dioxide levels in the atmosphere. This unit will frame the issue of climate change, and look at our current fossil fuel infrastructure and energy choices.

Activities

In this unit students will first address the NGSS standard ESS3-5 which states: 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. In order to meet this standard, students will need to organize data from graphs and simulations, identify relationships within the graphs and data sets and between the graphs and data sets, and then they will need to interpret the data to make future predictions from the climate. In order to make the predictions students will need to evaluate to what degree they are certain about their conclusions by considering the strength of the data that they are interpreting. This is quite a lofty task.

To start out the unit students' prior knowledge should be addressed. Holding a class discussion or taking a poll or producing a drawing to represent students' thoughts about the climate over time would be a good way to start out the unit. Using a graphic organizer such as a K-W-L chart to have students detail what they Know and What to Learn about the following questions: Do you think the world's climate has always been the same? In what ways could the climate have been different in the past? What variables could have affected the climate in the past? Are changes currently occurring in the world's climate? In what ways can we tell? Are weather and climate the same or different? After the lesson they could complete the "Learned" portion of the K-W-L chart.

At this point students would have already learned biology in a pervious course which covers geologic time when discussing evolution, however it would be important for students to have a refresher on the sense of geologic time to understand the scale at which some climate processes occur.

A great tool for students to investigate the changes of the Earth over time is the media viewer from HHMI's Biointeractive. This computer manipulative, which is accessible through the Internet or downloadable, allows students to view a time-lapse of the world and track different variables over time. They can see how the land mass has changed, temperature, CO_2 levels, oxygen levels, and many other things. Students can adjust time scales to see the world over the course of its entire history, the paleo earth, the ice age earth, or the "Warming Earth" which is from 1912-2012.

The class should be shown the general overview of the simulation and how it works to the class. Students should be shown how to manipulate the simulation and its controls. Students would then be put into groups of two, three, or four and will work to find a trend in the climate data such as temperature, CO_2, landmasses, O_2 levels, day length, etc. Each group will either be assigned a trend or allowed to pick a trend to investigate. This would be a way to differentiate between the abilities between the classes or within the classes. Students will work with their group to present the trend in their data to the class. They could make their presentation through a screen capturing program such as screen-cast-omatic or other screen casting programs, or students could stand and present the trend or pattern that they observed to the class. Students should focus on explaining the time scale of the trend, potential reasons why this trend could occur, what could be some of the effects of this trend, and lastly what is the current state of this climate parameter. During the viewing of the other groups' presentations, students should take notes on the variable is being presented, the trend being described, and the timescale of the trend. They should focus on how the variable changed over time. Students should see that CO_2 and temperature have fluctuated over time and the Earth's climate is dynamic on a long time scale. Students should reflect on their K-W-L and add any new questions or answers that they gained from the activity.

Next, the class will investigate the data from Mauna Lao Observatory which is a direct measure of atmospheric CO_2 that has been collected daily since 1958. This will afford the opportunity for the teacher to show how patterns and trends are observable in data and the importance of viewing data with a timescale in mind and the chance to view quantitative data. This data is also good to investigate because it comes from direct measurement. The Scripps Institute of Oceanography publishes their data and it is viewable in graphs of various timescales that include one week, one month, six months, one year, two years, and then the full record that goes back to 1958. Viewing the CO_2 following these progressions of scale will help to first highlight to the yearly fluctuation in the CO_2 levels. Students should be able to infer from their previous biology course that CO_2 rises in the winter when plants go dormant and decomposition of their leaves and biomass occurs and CO_2 dips in the summer when photosynthesis picks up again. It will then serve to show how trends look differently when viewed at different time scales.

A class discussion will be led to address questions such as: what happens when you view data at different scales. Why are scientists most confident about this data? Where could all of this CO_2 be coming from? Which time scale is important to consider when making climate projections into the future? What could be done to stem or reverse the increase in CO_2?

Students will then investigate a variety of data sets to make predictions about the Earth's climate in the future. Students will be divided into teams and each one of them will become the experts in regards to that climate trend. The class will be split into teams that will investigate the atmosphere, the cryosphere, or the hydrosphere. Within these three areas, the team will then be further divided and each student or pair of students will be given a particular data set. Students will then work, first independently to interpret their own data set, and then they will collaborate with the others on their team, to develop an overall picture of the types of changes and patterns that appear in their data.

For the students that are in the atmosphere team, they will be given CO_2 data since 2005 with the seasonal cycle removed, the indirect measurements from ice core data from

400 thousand years ago to present, a visual tour of 2006 CO_2 measurements (a computer model of one year in global CO_2), and following CO_2 in the atmosphere 2014-2015 (a 3-D view of global CO2 emissions). I will give the CO_2 data to the students that need more support or scaffolding in the classroom due to the fact that I would have already discussed the Mauna Lao observatory data with the class when we discussed scale. The atmosphere team will also need to look at temperature data in the form of a global heat map from 1880-2015, and last 400,000 years of temperature data. Another potential data sets could be the atmospheric concentration of methane, which will be an important point in a later activity when we investigate natural gas drilling.

The cryosphere team will be investigating the changes that are occurring in the land ice, sea ice, and permafrost. They will interpret satellite data from NASA showing the sea ice, pictures of the Antarctic and Greenland mass variation since 2002 from NASA, the global sea ice area from 1978 to present from NSIDC, gravimetry images of Antarctic ice, and satellite alimentary of Antarctica and Greenland.

For the hydrosphere/oceanography team they will have data in the form of different interactives, tables, and charts. There is a table from NASA that organizes the research on the rate of sea level rise, including the rate at which the sea level has risen and the +/- confidence of their information. Students will also analyze satellite data from 1993 to present for sea levels, ground data from 1870 to 2000 for sea levels, CO_2 levels and ocean acidity, frequency of flooding along US coasts 1950-1959 compared to 2010-2015, average global sea surface temperature 1880-2015, ocean heat content 1955-2015, and what the world would look like if the ice melted[30].

The individuals or the partners that are analyzing their data set will address the following from their data: Describe what this data set is measuring. What observations can you make from looking at this data? Describe any patterns or trends that you see in the data. How far back does this data go? Why don’t you think we have data past that time? It is important to consider time scale when interpreting these changes that are show on the data. Describe the change or rate of change that this data shows over the last 1 year, 10 years, 100 years, 1,000 years, 10,000 years, 100,000 years, 1,000,000 years, 1,000,000,000 years. Was this information collected the same way during each of the time scales or did scientists have to measure the information differently during different time periods? What type of errors or uncertainty could occur in measuring the data this way? Looking into the future, what do you predict will be the future effect of climate change on this measurement? Are these changes reversible or irreversible? What information do you have to support this claim? How confident are you in this prediction?

After each of the students has analyzed their individual data set, they will come together as a team. As a group they will share their findings from their data sets to their groups including descriptions of their confidence in their findings and their individual predictions for the future of their climate parameter. Next students will work as a team (atmosphere, cryosphere, and hydrosphere) to develop a snapshot of climate changes that are occurring or impacting their sphere.

The last part of this activity will involve a share out of this information about the climate changes within Earth's atmosphere, cryosphere, and hydrosphere. Students should make a poster or infographic to detail the trends in their data and their predictions for the future for their criteria and then further predict the implications are of these future trends. The teams will share out their findings in the form of a poster session and the other teams will take notes from the other groups to organize the findings from the other teams.

After students gather their data as teams and reason through their predictions as a team and communicate with the class it is the teacher's job to help the students process their findings. Important points to discuss would be the fact that there are cycles to some of the variables such as CO_2 and temperature levels. Other points to highlight would be how rates of change and time scales are important when describing changes. Lastly the most important point to have students consider are the relationships between the variables for example, having students see that temperature and CO_2 follow a very similar trend. To help students summarize between the data, they could be asked to compare and contrast conditions within the different spheres. They could then be asked which forecast they feel supplies the grimmest scenario. They could be asked which forecast do they have the most confidence in or the least confidence in and why. To finally conclude this discussion or analysis, students should be asked to discuss which changes are seen as reversible and irreversible and detail why.

Next students will learn about greenhouse gases and the greenhouse effect. There are a few great animations and simulations online, all which would function to show a similar outcome, that greenhouse gases trap heat. Recommended resources for investigating the greenhouse effect are the Gizmo from Explore Learning (which requires a license) entitled Green House Effect, The Green House Effect simulation from PhET from University of Colorado Boulder, the Green House Effect site from the EPA, or the Howard Hughes Medical Institute Greenhouse Effect Video. Without the greenhouse effect the Earth would be much cooler, so we need some greenhouse effect, but humans are adding more CO_2, which is increasing the greenhouse effect and leading to climate change. Students have already seen the evidence for observations that have led scientists to the conclusion that climate change is occurring and is largely being driven by anthropogenic CO_2 emissions. The next part of the unit will explain the process of global warming and show how CO_2 can lead to warming.

Students should be asked to develop their own model to show how the greenhouse effect works. They may be supplied with various materials to design and build a model that demonstrates how greenhouse gases or how surface albedo (the reflectivity of a surface such as white snow or darker dirt) can trap radiant energy. Materials such as plastic water bottles, glass jars, thermometers, water, timers, plastic wrap, various colored construction paper, alka seltzer or vinegar and baking soda to produce CO_2, or other materials should be supplied so that students may construct a device to measure the effect of CO_2 concentration or substrate color on temperature in a jar or bottle.

The next portion of the unit will focus on fossil fuels and the global energy demand. Students will be charged with the task of meeting the NGSS *HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*

In order to have students evaluate solutions for managing and utilizing energy and mineral resources, students will role-play in a game. Each student will take on the roll of an elected official and they will need to choose which processes should be used to extract different fossil fuels. Students will select a role card to represent motives of various politicians. The fossil fuel processes include strip mining for bituminous coal, mining for anthracite coal, natural gas fracking, and deep sea oil exploration. Students will have money to invest in the four mining or pumping processes and will need to invest 'tax dollars' to generate enough energy without causing too much environmental or social harm.

Students will start with money chips, social chips, and environmental chips, these will be used to pay for the cost of energy sources. Energy that is bought will supply energy but also will give the students CO_2. Certain events may cause them to gain or lose these chips.

Players will be given 10 money, 10 social, and 10 environmental chips to start the game. Players must each purchase at least 10 units of energy per round. Each player can make their own energy choices, but some players' choices may affect the other players. During a round, each player needs to generate at least 10 units of energy and must always have at least one deep sea drilling rig to provide gasoline.

After the energy is purchased, players need to exchange the appropriate amount of money, environmental, social, and CO_2 chips. The team then turns an event card and follows the instructions on the card. The events will describe some problem with the energy resource collection process, or social event, or political decision to be made. These events could decrease or increase the players' money, social, emission, or environmental chips.

At the end of the round, the player with the lowest CO_2 emissions will earn a bonus environmental chip. If any players generate more than 10 units of energy in the round, those players will earn one extra money chip to simulate energy exports. Players may purchase more social or environmental chips for 5 money chips each. If a player runs out money, they must keep track of how much debt they accrue. All players will get one more money chip at the start of the next round to simulate taxes. The game will be played until all of the event cards are used.

After all of the event cards are played students will need to get their score for the game. Their final score will be a tally of points with each money chip worth one point, social chips worth five points, environmental chips worth ten points, and each CO_2 emission will be a negative four points. Each student will need to total their points and reflect on how well they played the game individually and as a group. Students can compare their scores within their group and then compare between groups.

Student reflection questions would include: Do you think the point values were fair, pick one example value you that you thought was too low and one you thought was too high and explain why. How could you modify the rules to include investment in other energy options or better practices for fossil fuel extraction? Why do you think these energy options were not included in this game? What was it like working with other players that had other objectives? Which energy options did you prioritize, which did you avoid and why?

Conclusion

This is a very exciting unit because it gives me a chance to cover new material in the classroom and allows students the ability to use real data in their conclusions and predictions. I am really excited for the fossil fuel game because I know my students really enjoy competition, debating, and trying to prioritize the 'right' decisions, especially when there are so many variables to consider!

Appendix

The first standard: *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* - is addressed when students evaluate the climate data and make their forecasts.

The second standard: *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* – is addressed when students create their greenhouse gas model.

The third standard: *HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios* – is addressed when students play their fossil fuel game.

Link for Data Tables - https://docs.google.com/document/d/14x2sj7ls2tE2S7Ud53ECd17UllW9GA0CmNgGXDSEC58/edit

Link for Resources for Climate Change Evidence - https://docs.google.com/spreadsheets/d/1QWRPTzI12-QS87EswEsuE6KZKiRqGYbhiSlX006w8CY/edit?usp=sharing

Link for Fossil Fuel Game Information - https://docs.google.com/document/d/1EEOt72D9xCd4cXHgcXbcIyrOtJVjHh8c4Rdouw-bqL8/edit?usp=sharing

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