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Engineering Solutions to a Changing Climate

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Rational

As a teacher at a large comprehensive high school in New Haven, CT I teach phychem which is the ninth grade science course in the city. Phychem is a science course that focuses on two major topics a quarter. Topics covered in phychem include climate change, natural resources, waves, electricity and magnetism. The first quarter looks at earth's energy and matter cycles as well as weather and climate change. The unit presented here would come after a section on the greenhouse effect and how humans are impacting the climate system. Taking an engineering approach my unit will teach students about possible engineering solutions to climate change. Participating in this unit will be ninth graders or students taking phychem at both the college and honors levels. Phychem is a course designed for 9th grade students that follows the Next Generation Science Standards (NGSS). These standards incorporate both scientific principles and engineering practices in the classroom.

The 9th grade curriculum now includes a section on climate change. Students taking phychem at Wilbur Cross H.S. are impacted and will be impacted by climate change. As younger high school students from an urban environment they need to be exposed to local, national and global issues such as climate change.

Students can and will be affected by the changing climate of the earth. This year in phychem our anchoring phenomena for the weather/ climate and climate change unit was hurricanes. Also this year devastating hurricanes impacted many people including families of students at the school and in my classes. Though there is not conclusive evidence to say it was climate change, there is the increased potential for climate change to contribute to hurricanes through changing weather patterns and warmer air and ocean temperatures. A problem on all scales, it is important for students to learn about the mechanisms and need for solutions to climate change.

Due to the changing climate there is a great need for science, technology, engineering and math (STEM) careers in the future. Scientist will be needed to monitor, model and document the changing climate and mitigate impacts. Many engineers will be needed to generate solutions for better infrastructure as well as the most efficient alternative energies.

Climate change is important topic to address carefully because it can inspire a negative outlook. Students might have a pessimistic view that there is nothing that can be done with as problem as global as climate change. Through this unit, I want to inspire a need for solutions that are real to the students. A changing climate is already a problem and will soon be our student's problem to help solve. Creating informed passionate people is key to finding a solution.

What is Climate Change?

Climate change refers to changes to long term atmospheric conditions. The change to the climate occurring now is the increasing global average temperature due to anthropogenic positive radiative forcing. What anthropogenic positive radiative forcing means is that humans are causing the climate to get warmer. Radiative forcing can be explained as a gases' ability to affect the earth's energy balance. The earth receives energy from the sun which is an energy input and then loses energy as infrared radiation. Earth's energy balance is the relationship between the energy inputs and outputs. Greenhouse gases affect the earth's energy output by trapping more heat close to earth causing an average temperature increase.

Climate change is happening because humans are altering the composition of the atmosphere by adding large amounts of carbon dioxide and other greenhouse gases. Anthropogenic or human caused sources of carbon dioxide include the burning of fossil fuels and deforestation. While carbon dioxide (CO_2) is the most prevalent, it is not the only greenhouse gas. Other greenhouse gases include nitrous oxide (N_2O), methane (CH_4) and water vapor (H_2O). [1] Concentrations of carbon dioxide, methane and nitrous oxide have all increased in the atmosphere because of human activity since 1750. One statistic shows that, "In 2011 the concentration of these greenhouse gases were 391 ppm, 1803 ppb, and 324 ppb and exceeded the preindustrial levels by about 40%, 150% and 20% respectively." [3] This information is concerning because these levels of carbon dioxide, methane and nitrous oxide are higher than they have been in the last 800,000 years according to ice core data. [3] Ice cores provide this data through ancient air bubbles trapped in the ice which tell us past atmospheric conditions.

Carbon dioxide and other greenhouse gases keep the planet at a livable temperature through the greenhouse effect. This effect is where shortwave radiation from the sun reaches the earth's surface, warms it and is reradiated as long wave radiation. This long wave radiation is trapped by greenhouse gases in the lower atmosphere or lost to space. Human contributions of carbon dioxide and other greenhouse gasses to the atmosphere however, absorb outgoing radiation are causing an increase in the global average temperature.

There is no question the climate of the earth is getting warmer.[2] The increasing temperature as well as its effects are setting records for the most recent decade to millennia. Effects we are already seeing include warming of the ocean, receding glaciers and decreased extent of the polar ice cap, rising sea level, and warmer surface temperatures. [3]. Each of the last three decades has been successively warmer at the earth's surface than any preceding decade since 1850. [3]. Globally averaged combined land and ocean temperature data as calculated by a linear trend show a warming of 0.85 degree C over the period 1880 to 2012 According to the observed globally averaged combined land and ocean surface temperature anomaly data from 1850 - 2012 there is a clear upward trend toward higher temperatures [3].

There are many projected effects of climate change that are very likely occur by the late 21st century. These changes to the earth include: warmer and/or fewer cold days and nights over most land areas; warmer and/or more frequent hot days and nights over most land areas; warm spells/heat waves frequency and duration increases over most land areas; heavy precipitation events increase in frequency, intensity and or amount of heavy precipitation; and increased incidence and/or magnitude of extreme high sea level.[3] Other effects include the ocean temperature rising. The ocean is warming the fastest near the surface and the first 75 m of depth at a rate of about 0.11 degrees C per decade since 1971 to 2010 according the the IPCC [3]. Effects to the cryosphere include the Greenland and Antarctic ice sheets have been getting smaller, glaciers all over the world are disappearing. [3]. Due to both ice melting and warmer temperatures which cause thermal expansion sea level has gone up almost 20 cm from 1901 to 2010. [3] A less obvious effect of the increasing concentration of CO_2 in the atmosphere is ocean acidification. “The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide (a weak acid in water), causing ocean acidification and a drop in pH according to the 2013 IPCC.

Climate change is a problem for many reasons. There are many potential effects of this warming including sea level rise, melting ice caps, changing spatial distribution of disease vectors, ocean acidification and changing weather patterns. These are only a few of the many different known impacts of climate change. Each of these different effects of climate change will put stress on different areas of infrastructure from flooding coastal roads to diseases increasing their range.

What Can be Done?

What can we do about such a global problem? According to the Intergovernmental Panel on Climate Change there are two major approaches for dealing with climate change: mitigation and adaptation. Mitigation refers to reducing sources and increasing sinks [4]. Adaptation is changing to deal with the effects of a changing climate. In order for any solution to be put in place it need to be an equitable and economically fair solution [4].

The unit plan presented here will focus on mitigation. The definition of mitigation when talking about climate change uses the words sources and sinks but first we need to explain the carbon cycle. Just like water, carbon also cycles. Carbon sinks include the atmosphere, photosynthesis, and ocean while sources of atmospheric carbon include greenhouse gasses emitted by respiration, deforestation and burning fossil fuels. Humans are altering the carbon cycle by releasing carbon stored for long term underground stores such (fossil fuels) and burning them for energy. Fossil fuels are fuels such as coal, oil and natural gas. Humans are moving large amounts of carbon from long term storage to the atmosphere as CO_2.

Solutions that mitigate climate change can encourage the use of low greenhouse gas emitting energy or the capture and long term storage of carbon dioxide. Some potential alternative energy sources could be solar energy, nuclear energy, wind, hydrogen fuel cells. Carbon sequestration options include absorption towers, burning fuel in pure oxygen (to help capture the CO_2), deep ocean storage and using biological organisms such as trees, algae, and other plants to take up the excess carbon dioxide. Alternative energy sources are also required because our current dependence on fossil fuels is not sustainable. Fossil fuels are not a renewable resource so there is a need for different energy sources before they run out and it is no longer cost effective to harvest them. Also important is the need for energy sources that do not release greenhouse gases like carbon dioxide and nitrous oxide into the environment contributing to a changing climate.

Carbon sequestration is a potential solution to carbon dioxide being put into the air from fossil fuel combustion. Carbon sequestration is the capture and storage of carbon out of the atmosphere, most likely underground under high pressure. This method could be used in industry to capture the CO_2 released and prevent it from entering the atmosphere. Carbon capture and storage has three parts which include first capturing the carbon dioxide, then moving the carbon dioxide and finally storing the carbon dioxide. Long term storage would occur in one of two places. Empty oil and gas fields or deep saline aquifer formations [5] are potential candidates for long term storage. One idea is to replace smoke stacks with absorptions towers and burning coal in pure oxygen and then using underground storage. By burning coal in pure oxygen it becomes easier to separate the carbon dioxide from the exhaust (which is a majority Nitrogen gas and other compounds) [13]. In the absorption towers one would have chemicals to isolate carbon dioxide and absorb it. The other tower would remove the carbon dioxide from the absorbing chemicals. [13] Potential engineering solutions to climate change do exist.

Alternative energy sources are those that do not use up nonrenewable natural resources or harm the environment. A short list of some alternative energy sources includes: solar, nuclear, hydroelectric, wave, biofuels, geothermal, wind, biomass, tidal and hydrogen. In 2017 renewable energy made up 11% of primary energy consumption in the United States. The breakdown for this 11% is as follows: 2% geothermal, 6% solar, 21% wind, 4% biomass waste, 21% biofuels, 19% wood, and 25% hydroelectric. [15]

Solar energy can be harnessed and used in two different ways. First is passive solar energy which may be used to heat water or directly heat a building. Passive solar energy does not require a mechanical system to work. Active solar energy uses photovoltaic cells to convert solar energy to electrical energy without the use of a turbine. There a both advantages and disadvantages to solar energy. First is that operation produces very little greenhouse gas emissions and these technologies also work anywhere there is sun. A major drawback of solar energy is that it only works when the sun is out so power is limited or unavailable at night or when it is cloudy, unless systems build a reliance on batteries.[7] In 2002 the projection for the growth of the solar energy market was that it would grow 1 gigawatt per year by 2010. By 2010 this goal was exceed by 17 times and the use of solar energy is increasing. World solar photovoltaics installation is increasing exponentially and the cost of solar panels is coming down.[16]

Nuclear power is created by the process of fission. Fission is where the nucleus of an atom is split releasing large amounts of energy. The heat energy is then used to produce steam and turn a turbine powering a generator. An advantage of nuclear is that it is such an abundant form of energy that is less polluting, especially if the nuclear waste can be reprocessed, however it also has a major drawback that a major malfunction could be catastrophic for human life and the environment.[7]

Hydroelectric energy is electricity generated by using flowing water usually from a dam to turn a turbine powering a generator. China has the world's largest hydroelectric power plant providing electricity for the populations growing demand for power. Hydroelectric energy has advantages including not releasing any carbon dioxide in the electrical generation process once built and providing a steady supply of electricity. Disadvantages of hydroelectric energy include environmental and human impacts of damming a river and flooding the area behind it to create a reservoir.[7]

Wave energy is where the energy of ocean waves is captured at or below the surface. Waves are caused by wind moving over the surface of of the ocean in windy areas, which creates great potential to extract the energy of the waves. (ocean wave energy article). Benefits of wave energy are that they do not produce pollutants such as carbon dioxide but they are limited costal locations where large waves exist.[7]

Biofuels are fuels that come directly from living matter such as ethanol or biodiesel. Biofuels are an attractive solution because the plants used to make the biofuel take carbon dioxide out of the atmosphere even though they still release some when burned making them carbon neutral. The problem with biodiesel is that plants are energy intensive to grow and harvest and process and result in both land use changes and greenhouse gas emission during production.[7]

Geothermal power is derived by using heat stored underground to turn a turbine. Similar to the other alternative energy sources geothermal does not produce CO_2 while making electricity. Disadvantages of geothermal however include that it is limited to specific geographic locations.[7]

Wind energy harnesses the power of the wind to turn a turbine. Wind turbines may stand alone or be found in wind farms. Wind energy is not only good because it does not release any CO_2, but because it is also a renewable resource. Some cons of wind energy are that it is noisy, harms wildlife and is only efficient in certain locations.[7]

Biomass energy is the direct burning of plant and animal matter for heat. Burning wood for cooking is one example of biomass being used for energy. It is considered a better alternative to fossil fuels because it releases less CO_2 than fossil fuels when burned due to the uptake of CO_2 to grow the biomass. Problems with biomass energy include things such as indoor and outdoor air pollution, extensive land use, and the potential for deforestation.[7]

Tidal energy comes from energy produced by the ebb and flow of the tides. Here water turns a turbine underwater as the tide goes in or out. A dam may be built across a bay to turn the turbine or the turbines could be placed underwater. Advantages include the production of power and the CO_2 prevented from entering the atmosphere. Problems with tidal power include the disruption of the seafloor habitats and limitations to areas with significant ties.[7]

Hydrogen gas could potentially be used as a completely clean fuel. The products produced from combustion are only water vapor and warm air. Hydrogen gas may be harvested from natural gas and other fossil fuels or through electrolysis. Electrolysis is the process of using electricity to split water into hydrogen and oxygen. Like all the other alternative energies there are both pros and cons to the use of hydrogen gas as an alternative energy. Pros include the clean emissions during combustion. However generating the hydrogen gas for fuel is not a fossil fuel free process requiring either fossil fuels or other source of energy for electrolysis of other means of production. With all these potential sources of energy and even more not mentioned here there is potential to severely reduce the carbon input to the atmosphere.[7]

Why teach about engineering?

All of the solutions mentioned in the previous section require engineers to make them happen. We are living in a changing world, which will require many engineering solutions for both adaptation and mitigation. The new science curriculum has a focus on engineering incorporating both scientific and engineering practices. In this unit we will focus on the engineering design process. The engineering design process begins with a problem, then solutions are brainstormed, one is selected to build a model which is then tested and evaluated then the design is improved. The testing evaluating and improving steps may be repeated many times before the idea is shared. Engineering design process is different than the scientific method which is not solution oriented but more a method for collecting information. It is important to teach the engineering design process because many engineers will be needed in the future for both the effects and mitigation strategies for climate change.

What is green engineering?

The engineers of the future will need to be more focused on green engineering to deal with the many problems facing the earth including waste disposal, limited resources and pollution. Example of these problems include plastic waste disposal, liabilities of fossil fuels and heavy metal pollution. Green engineering uses science and technology to accomplish sustainability. In order for a product to be sustainable its whole life cycle needs to be assessed. A products life cycle includes its acquisition (collection of raw materials), manufacturing, distribution, use and end of life. It is important to do a complete life cycle analysis for a product to determine its sustainability.

One example of considering the entire life cycle is provided for wind power. What are the inputs that produces greenhouse gasses for a windmill? Inputs include concrete for the base, mining for the metals required, energy for both the transport of materials and assembly which comes from burning fossil fuels releasing carbon dioxide into the atmosphere. Use of the windmill produces energy with little green house gas production At the end of the windmill's life cycle it needs to be considered if any of the parts be recycle? What parts need to be disposed of and what are the consequences of the disposal? Such as toxic leachate or methane being released from landfills. Also how will the parts be transported. Considering a windmills whole life cycle brings up the question does it actually create enough clean energy to be considered sustainable given the inputs, output and disposal.

Principles of green engineering can focus the products design on different aspects of sustainability. One of the principles of green engineering as presented by the authors of the article *Through the 12 Principles of GREEN Engineering* is preventing waste rather than treating the waste once it is made. [12] One examples of this includes burning low sulfur coal rather than using scrubbers which remove the sulfur from the smokestacks.

Another principle of green engineering from the same article is designing products for easy separation of materials at the end of a life cycle. Separating a product at the end of its life cycle can require energy or use of toxic chemicals. If the product was designed to be easily separated these harmful processes could be reduced or even eliminated. [12]

Using local resources such a material or energy sources is one other tenant of green engineering. By following this tenant it minimizes the need for transport of material and using less sustainable methods for generating energy. One example could be building a wind farm rather than a coal powered power plant in a naturally windy location. Rather than needing to transport the coal from a location far away, the wind that is there already is harnessed for energy both reducing the amount of fossil fuels used in transportation and generation of energy.

Currently many products reach the end of their life cycle not because all of the parts are non-functional but they are perceived as no longer stylistic or the technology has become obsolete. Designing products for a "afterlife" is another principle of green engineering. An example of this would be to reduce waste, parts that are still functional or valuable would be collected for reuse. [12]

The principles of green engineering need to be a focus to help reduce environmental problems occurring now and prevent more in the future. By considering a products whole life cycle from acquisition to end of life will help increase sustainability and dramatically reduce the amount of waste created.

What are some past environmental successes?

Climate change is not the first major global scale environmental problem. Past environmental problems that have been addressed on a national or global scale include the use of DDT (dichloro-diphenyl-trichloroethane) being banned, the hole in the ozone layer and the use of chlorofluorocarbons (CFC), and excessive amounts of lead in the environment. DDT was in the 1940's the first modern synthetic insecticide and was used to control mosquito borne illness such as malaria. Initially it was wildly successful and its use pervasive. In 1972 however the U.S. EPA banned the future use of DDT because of its negative effects on wildlife and potentially human lives. The discontinued use of DDT was brought about because of increasing evidence that insects were becoming resistant to it and its environmental effects were very toxic. In addition, Rachel Carson's book *Silent Spring* brought out public concern of the improper use of pesticides and efforts to control this. Several disconcerting fact about DDT include its persistence in the environment, accumulation in fatty tissues and that it can travel long distances in the upper atmosphere. [9]

CFCs are compounds that were once used as refrigerants coolants and aerosol propellants. These compounds were eventually found in the stratosphere where they break down ozone. Stratospheric Ozone is an incredibly important compound that protects the earth from harmful cancer causing ultraviolet-C-radiation. Research found that CFCs were reducing the concentration of ozone above the Antarctic. In 1987 at the Montreal Protocol, 56 countries agreed to cut then phase out CFCs. This is significant because it was an early and successful example of international cooperation on reducing environmental problems.[10]

Lead in the environment is harmful to both children and adults causing lower IQs in children as well as lower learning and memory abilities. In adults lead negatively affects the brain, kidneys and cardiovascular system. Lead however is incredibly useful and is released by many industries including smelting, metal mines, and waste incinerators. Lead however was not always recognized and regulated as a harmful metal. In 1922 lead was introduced to gasoline. Many years later a scientist Clair Patterson concluded from ice core samples in in Greenland that Americans had 100x the natural levels of lead in their blood. Then in 1970 the Clean Air Act required the EPA to lower emissions of harmful pollutants including lead 90% in the next few years. However it was not until 1990 that lead was banned in gasoline and in 2002 lead levels in American children ages 1-5 decreased 80% from 1976 to 1999. [14]

Both of these success stories end with changes to regulation and concerted efforts to work towards fixing an environmental problem. It has been done before and can be done again with humans working together to mitigate climate change through not just policy but engineering solutions. Even now there is a great movement towards renewable energy generation industries. For example in 2010 investments in renewable electricity generation passed fossil fuels and in the US in 2015 of all the new electricity generation 32.8% was from solar and 38.2% from wind. [16] There is good reason to view climate change as a world problem that can be confronted.

Content Objectives

Day 1

- Students will be able to explain and apply the engineering design process. (Activity 1, the engineering process)
- Students will be able to reference past environmental problems that have been mitigated

Day 2

- Students will be able to identify the two ways to decrease the amount of carbon in the atmosphere: decreasing sources and increasing sinks (Activity 2, carbon dioxide removal)
- Students will be able to provide methods for both decreasing carbon sources and increasing carbon sinks.

Day 3

- Students will be able to identify and explain the pros and cons of the following alternative energies: solar, nuclear, hydroelectric, wave, biofuels, geothermal, wind, biomass, tidal and hydrogen.

Day 4

- Students will be able to use the engineering design process to design the most efficient wind turbine to generate the most current. (Activity 3, alternative energy, wind power)

Day 5

- Students will be able to complete a life cycle analysis and apply principles of green engineering.

Classroom Activities

Activity 1 Engineering process

Index Card Challenge

Materials

- 6 of the same textbook
- 150 index cards (25 per group)
- 12 feet of scotch tape (2 feet per group)
- Engineering Design Process Worksheet

Begin activity by showing pictures of bridges. Then in partners discuss what was the process to behind building the bridge? Did they just start building? Why did they even build a bridge? As a class discuss the answers from each pair. Then present the engineering design process. Draw a flowchart on the board of the different steps. First there needs to be a problem such as how can many people cross a river without a boat? Second solutions need to be brainstormed for example a bridge above the water or a floating dock. Third, one idea is selected. Fourth, the design and structure is created. A model of the bridge above the water could be built. Fifth the creation needs to be tested. The sixth step is to improve and tested again until it is ready to finally be shared. Many models for a bridge could be built and tested before the final plans for the bridge are ready to be shared.

Students will follow this process on their own with the following challenge. How can you build the tallest structure to support a textbook only using index cards and tape. Following the engineering design process on their worksheet students will identify the problem. Brainstorm solutions create and test and create and test again until they are ready with their final product.

Activity 2 Carbon Dioxide removal

Is it possible to remove carbon dioxide from the air?

Materials

- Air quality meter that can detect carbon dioxide levels (one per group)
- Toilet paper tubes (2 per group)
- Coffee filters (6 per group)
- Activated charcoal (same amount for each group
- Hot glue
- Lab Worksheet

In this challenge, students will be asked to design and test a filter to remove carbon dioxide from the air. This lab will come after a short lecture on carbon sequestration. Using the tube, coffee filters, hot glue and activated carbon students will design a filter. Next they will test whether or not their filter works. By taking several carbon dioxide level readings. They will be asked to take the measurement of the CO_2 in the air in the room, the amount of CO_2 at the end of the tube when they breathe through the empty tube and the CO_2 level after they breathe out into their filter. Using this information they will conclude whether or not their filter works and write a conclusion including evidence.

Activity 3 Alternative Energy Wind Power

Materials

- Kidwind Advanced Wind Experiment Kit (vernier) [11]
- Multimeter
- Separate fan to simulate wind

In this lab activity students will design the blades of a fan that generate the most power. Students will be given manila folders to cut out their designs from and tape to attach the fan blades the dowels. The dowels connect with the circular centerpiece which attaches to the fan motor. Once the students are ready to test their design the fan will provide the wind to make the model turbine spin with the students fan blades and the multimeter can be used to measure the current generated. The engineering design process will be followed and the students will have the opportunity to optimize their design.

The second half of this activity will be a simple life cycle activity where student will identify what the inputs, outputs and waste disposal of a wind turbine by making a charts and having a discussion what would need to be true for a wind turbine to be a green efficient solution for alternative energy.

Endnotes

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Appendix

HS-ETS 1-4

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

HS-ESS 3-1

Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ESS 3-2

Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost –benefit ratios.

HS-ESS 3-4

Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-ETS 1-2

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems than can be solved through engineering.

HS-PS 3-3

Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.