Yale National Initiative
to strengthen teaching in public schools®

Curriculum Units by Fellows of the National Initiative
2019 Volume IV: Energy Sciences

Assessing Chicago's Carbon Footprint One Step at a Time

Curriculum Unit 19.04.06, published September 2019
by Taissa Lau

Introduction and Rationale

“By bringing fossil fuels to the surface and burning them, we are returning the carbon and oxygen to their original state. Within a few short generations we are consuming materials that were formed and concentrated over geologic eras. There was probably never more CO_2 in the air at any time in the past billions years than today.” -Roger Revelle, 1968

In 2000, it was published that Chicago, a city of 2.9 million residents, emitted 12 tons of carbon dioxide equivalents of greenhouse gases per capita. That’s a total of 34.7 million metric tons! In comparison, the amount per capita in Chicago was about double that of New York or London’s per capita emissions at that time. 91% of Chicago’s emissions were sourced from electricity, natural gas and transportation.[1] The significance behind these numbers lies in their relation to energy. In a review by NASA, it was declared that 97% of climate scientists agree that the climate-warming trend over the past century is most likely due to human activity, specifically humans need for energy.[2] As long as humans continue to use fossil fuels for things like electricity, heat and transportation the likelihood of reducing the impact of human activity on climate change is slim.

If you were to ask most students in my 8th grade Physical Science class what climate change is, they would likely tell you that it is something that is bad for the environment and it is making the world very hot. They would also probably reference their own experience with Chicago’s unpredictable weather patterns and assume the cause is attributed to climate change. While there may be some truth in their thoughts, it’s certainly not a complete understanding of what climate change is nor does it allow them to realize the causes or implications of this paramount issue.

The unit is comprised of five topics that all relate to climate change. The beginning of this unit is designed to address the foundational principles of energy. Students will first define the types of energy (i.e., kinetic and potential) and their behavior. Next, they will move on to exploring the principles of energy conversion and transfer by examining current nonrenewable and renewable energy sources and how humans harness energy for usage. Finally, students will end by assessing their hometown’s effect, implications and response to greenhouse gas emissions. Their assessment of the city will start with analyzing how human activities contribute to the rising greenhouse gas emissions, research on how the city can and has been lowering their emissions and finally propose innovative ideas to continue to move toward a carbonless future of energy in Chicago.

This unit is designed for students at Tarkington School of Excellence, a Chicago Public School within the Academy of Urban School Leadership network located on the southwest side of Chicago. The population of students is made up of approximately 954 students, of which 91% are considered low-income. The student demographics are approximately 77% Hispanic and 22% Black. About 13% of the student population receives special education services and approximately 30% of students receive bilingual services. This unit was designed for approximately 100 eighth grade general education students. Prior to the 2019 school year, these students had minimal exposure to science classes in kindergarten through fifth grade and only began attending science as a core content class in their sixth grade year. The students have had minimal exposure to the scientific principles of energy, energy sources and climate change. This unit is designed to align with the *Next Generation Science Standards*, which has been adopted by the state of Illinois for use in science education.

Content Objectives

Defining Energy

Generally speaking, energy is most often defined by textbooks as the ability to cause change or do work. What I have discovered is energy is much more complex than that. Energy, albeit abstract, is relevant to all disciplines of science and applies to all known natural phenomena. The reason it is applicable to all natural phenomena is because it is always conserved. Any process that increases energy must be coupled with another process that decreases energy. This reasoning allows scientists to hypothesize undetected processes opening the field for more scientific discovery.[3]

Students develop their own conceptions of energy long before they are explicitly introduced to it in my classroom. Most often students' preconception of energy is that energy is only present in living things or changing things. This does not align to the complete scientific understanding of energy. Thus, before indulging on any topic where energy is the driving concept, it is important to first define energy in a way that will be helpful to reference.

Energy is most easily classified into two different overarching types; kinetic energy and potential energy. Kinetic energy is energy associated with movement. It can be quantified using the formula $\frac{1}{2}mv^2$, where m represents the mass of the object and v represents the velocity of the object. From this equation, we can deduce that the quantification of kinetic energy is proportionally related to the mass and velocity of an object; as one increases so does the other. Potential energy is energy associated with height and often referenced as stored energy. Potential energy can be quantified using the formula mgh, where m represents the mass of the object, g represents the acceleration of gravity and h represents the height of the object above a reference height. Again, the relationship between energy and these variables is proportional.

There are other forms of energy that fall under the overarching categories of potential and kinetic energy. For example, kinetic energy can be observed in the forms of mechanical, light, electrical, thermal or sound energy. Potential energy is associated with elastic, chemical, nuclear and gravitational energy. Students are typically most familiar with gravitational potential energy, so in thinking about carbon emissions it is important to introduce students to other types of stored energy like chemical energy. An important characteristic of any type of energy is that it can be transformed, which we will look at in more detail in the next section.

Energy Transformation and Conservation

When you walk into a dark room most likely the first thing you will do is look for a light switch. You flip the switch and instantaneously the room fills with light. You probably don't think about the processes that are involved for this simple luxury to occur. Humans are constantly interacting with energy all the time. As mentioned in the previous section, there are different types of energy but regardless of what type of energy it cannot be observed directly with the eye. What we as humans do observe about energy is the result of energy transfers and transformations.

What may be hard for students to wrap their head around is the idea that energy is not a physical substance. When thinking about energy conservation, one must first define the system they are observing. There are two types of systems, closed systems and open systems. In a closed system, as processes occur, the amount of energy should remain the same at the beginning and end of the process(es). On the other hand, in an open system the initial quantity of energy that you start with may change as the energy is transformed into other forms of energy leaving that particular system and entering a different system. It is also possible that the initial quantity of energy can increase and in that case it would still imply the system is an open system and energy from another system is entering the observed system.

In everyday life, we mostly observe examples of energy transforming and transferring between different systems. For energy to be transformed, it changes from one type to another. Energy is never lost, though. An example of this would be the chemical energy in a battery, which transforms into electrical energy in a flashlight as it shines, which then emits light energy and thermal energy. The light and thermal energy are the same entity of energy that was initially stored in the battery but that energy is now expressed as two different types of energy as the battery powers the flashlight. The ability of energy to be transformed into the different forms of energy is what makes energy so critical for life. Humans rely on energy transformation to sustain our life in many ways. We utilize energy from the food we eat to carry out complex life processes, we use electrical energy to power our electronics, chemical energy is used for transportation modes, etc.

When talking about carbon dioxide emissions, we can further explain energy transformation throughout the chemical process of combustion of fossil fuels. We as humans burn fossil fuels so that the result is energy that we can use to carry out technological processes like providing heat for homes and buildings, running engines or producing electricity. In the combustion of fossil fuels, hydrogen molecules from the fuel and oxygen molecules in the air collide with enough speed that they break apart releasing the chemical energy stored in the bonds. Because the free atoms are close to each other, they begin to attract one another again in such a way that they form the lowest available potential energy arrangement. The difference in potential energy from the end state to the beginning state is typically manifested in even faster motion of the molecules.[4] The resulting higher temperature means that the molecules have greater kinetic energy, which can then be used to initiate other processes. For example to generate electricity, the hot gases can interact with water turning it to steam which in turn will transfer the steam molecules' kinetic energy to a turbine in a generator transforming the energy into electricity for use. In this process, we started with chemical potential energy in the fossil fuel, it transformed into kinetic energy in the form of heat, which then transformed into chemical energy as it heated water into steam. The steam transformed into mechanical energy as it turned the turbine.

Finally, the product of the initial energy was given off as electrical energy and thermal energy.[5] This is just one example of how humans are able to harness energy from fossil fuels. Subsequent sections will go more into detail about what other sources of energy are available and how energy is harnessed from them.

Nonrenewable Energy: Fossil Fuels

Nonrenewable energy refers to primary sources of energy that cannot be replenished once they run out. The most common types of nonrenewable energy sources are oil, natural gas and coal. These three types of sources are considered fossil fuels because they are the remains of plants and animals from millions of years ago.

Oil

Oil is a hydrocarbon, meaning that it is composed of hydrogen and carbon. It is formed from when dead organic material, typically plankton, mixes with inorganic material and sinks to the bottom of the ocean. This mixture continues to get buried by sediment and becomes sedimentary rock. The sedimentary rock is also known as organic shale. As this shale continues to be buried and increased in pressure it turns into a substance known as kerogen and this type of shale becomes known as oil shale. “If temperatures of the kerogen are greater than 90°C but lower than 160°C, the kerogen is transformed into oil and natural gas.” In order to accumulate, there must be some sort of reservoir with a top layer that does not allow the oil or natural gas to escape. Oil eventually rises through small pores in rocks where it must be contained in a reservoir until is drilled into and obtained by humans.[6]

From oil we can make petroleum that is used in gasoline, which means it is essential for use in transportation. “Gasoline is the most consumed petroleum product in the United States. In 2017, consumption of finished motor gasoline averaged about 9.33 million b/d (392 million gallons per day), which was equal to about 47% of total U.S. petroleum consumption.” In an engine, there are different parts to it that allow fuel to enter and begin a combustion reaction by also allowing air into the same compartment. Once the combustion reaction occurs, the product provides the kinetic energy needed to make the mechanical processes of the vehicle work.[7]

Natural Gas

Methane is the equivalent of natural gas. Methane is composed of hydrogen and carbon, making it a hydrocarbon. Natural gas is formed in the same manner as described for oil. The only difference is the temperature range for its formation. Natural gas can form at temperature ranges of greater than 90°C.[8]

“Most U.S. natural gas use is for heating buildings and generating electricity.” Once natural gas is extracted for use, it is transported via pipelines to facilities where impurities are extracted and a combustion reaction chamber is used to power a steam turbine or combustion. The turbine then generates electricity for human use. Natural gas can also be used for cooking and heating homes via a central heating system.[9]

Coal

As plant matter dies and eventually becomes buried, anaerobic bacteria will begin to decompose the matter. It can accumulate for thousands of years forming several meters of decayed plant matter. As time continues to pass and more matter continuously buries the matter, increasing pressure and temperature will transform through a cycle of different types of coal. More time will equate to a higher quality of coal. Each type of coal releases different amounts of CO_2.[10]

About 27% of electricity generation came from coal in the U.S. in 2018. Power plants burn the coal to create steam that in turn will power a turbine to generate electricity. In addition to be used for electricity, coal has other uses. It can be used to create steel or it can be turned into other gases or liquids to be used in fuels or other products.[11]

Renewable Energy: Solar and Wind

Renewable energy is energy that can be replenished naturally. Some examples of renewable energy sources include: solar, wind, hydropower, geothermal and biomass. "In 2018, renewable energy sources accounted for about 11% of total U.S. energy consumption and about 17% of electricity generation."[12] Using renewable energy sources could significantly reduce our carbon emissions, but I will go further into detail on that in future sections. In this unit, I will introduce students to the different sources of renewable energy but we will dive deeper into exploring sun and wind energy because these two types have the most implications for Chicago energy.

Solar Energy

"Solar Energy is, in fact, the only renewable resource that has enough terrestrial energy potential to satisfy a 10-20 TW carbon-free supply constraint in 2050."[13] In other words, utilizing solar energy alone would be enough to provide a carbon-free solution to energy usage on a global scale. The U.S. is responsible for about 3 TW of this total energy supply. So, why don't we? One issue is a mismatch of supply and demand. Solar energy is intermittent since it is only available for part of the day. At night and in the winter, when the demand for heat is high, solar energy is not as widely available. A second issue is the amount of land needed to harness the sun's energy. If we consider the U.S. alone, we would need to cover a land area relative to the size of Iowa in order to produce enough power for just the U.S.'s energy use. Despite these two disadvantages, the advantages are compelling. Solar energy is free, limitless, widely dispersed and has a low-environmental impact. A trending issue that is continuing to be researched is energy storage from solar power. One of the more popular ways to currently harness the sun's light energy is using photovoltaic cells. Photovoltaic cells are made of many silicon units that are doped with phosphorus or boron. This doping gives a junction that produces a electric field to eventually send electrons through to a circuit in order to create an electric current to provide electricity. Other ways to harness solar energy include solar thermal to produce heat and concentrated solar power to also produce electricity.[14]

Wind Energy

According to Nate Lewis's research, the "offshore electrical power potential of wind is larger than 2 TW".[15] Again, this just about matches the amount of energy supply the U.S. is currently using. One of the disadvantages to offshore wind turbines is transmission: transporting the energy to onshore facilities for supply. This idea of mismatched supply location and demand location continues to play a role when analyzing "hot spots" for harnessing wind energy. Of course, energy storage is also still a challenge in utilizing wind energy since it is another source, just like solar, that requires use after generation. Another implication of using wind energy that is still being studied is the effect it would have on local weather and surface temperatures. By harnessing wind, we are mixing different energy levels from the atmosphere. "According to temperature readings from one of the oldest wind farms in the U.S., near Palm Springs, California, the turbines make it warmer at night and cooler during the day, generally speaking."[16] This effect on surface temperatures could have other impacts, but more research is needed to prove any correlations between wind turbines and weather and climate. One definite environmental impact human's use of wind energy can have is reducing the emissions of carbon dioxide, thus giving this harnessing source contention to be at least one solution to climate change. In order to harness the energy of the wind, the blades are turned by the wind producing kinetic energy. That energy turns a shaft, which transfers the kinetic energy to a generator to generate electricity.[17]

Earth's Rising Temperature

Over 80% of America's energy is supplied by the combustion of fossil fuels.[18] Combustion involves burning a hydrocarbon by quickly reacting it with oxygen and producing carbon dioxide, water and heat. The fossil fuels we use to produce our energy are all examples of hydrocarbons.[19] Burning fossil fuels is the first contributing factor to the rise in our global temperature. Typically, nature regulates the amount of CO_2 in the atmosphere through natural process. This is known as the carbon cycle. In a slow carbon cycle, it takes millions of years for atmospheric carbon to move between the components of Earth's system. Carbon is stored in fossils and can remain there for millions of years.[20] Humans are the major disruptors of this natural process though. As humans continue to burn fossil fuels, they continue to increase the levels of carbon dioxide in the atmosphere. A full analysis on the effect of humans burning fossil fuels requires some history. The first point of history to consider is the Industrial Revolution, which started in 1769 when James Watt patented his steam engine. Britain's use of coal increased two fold every 15-20 years from 1769 to 1850. Coal was "used to make iron, to make ships, to heat buildings, to power locomotives and other machinery, and of course to power the pumps that enabled still more coal to be scraped up from inside the hills". The success Britain experienced with coal production spread throughout the world, and even when coal production slowed down in Britain it still increased across the rest of the world.[21] The second point in history to consider is data collected by Charles David Keeling. Keeling was one of the pioneers in analyzing atmospheric carbon dioxide levels. In 1959, Keeling began monitoring carbon dioxide levels atop Mauna Loa in Hawaii. At that time, the average concentration of CO_2 in the atmosphere was 316 parts per million (ppm). As Keeling conducted his research, each year's measurement of the CO_2 level increased. By 1980 it was about 345 ppm and by 2019 it rose to 409 ppm.[22] His data became known as the Keeling Curve, which provided clear evidence that atmospheric CO_2 levels were increasing.[23] Considering the data, it supports a correlation between an increase in energy production by technologies and an increase in carbon dioxide levels.

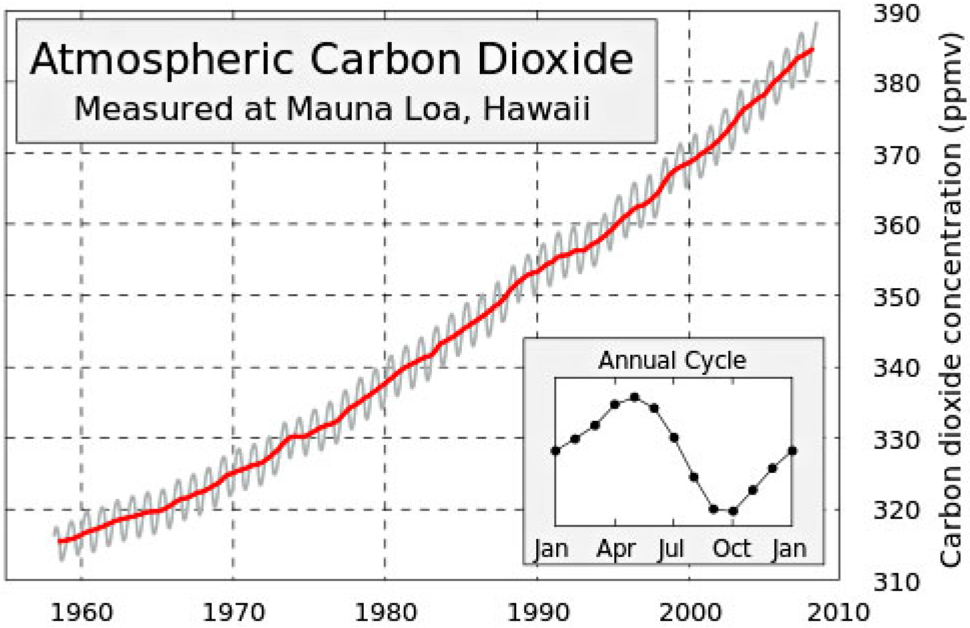

Figure 1. Keeling Curve displays the CO_2 levels from atop the Mauna Loa research facility. Source: Mauna Loa Observatory, https://www.esrl.noaa.gov/gmd/obop/mlo/ (Accessed July 16, 2019)

How does carbon dioxide relate to global temperatures? First, we must understand the system we live in, Earth. A blanket of gases called the atmosphere surrounds Earth. This atmosphere separates Earth from outer space. It surrounds the Earth and is made up of gases and is a huge factor in what allows Earth to be habitable. There is a multitude of different gases that make up the atmosphere: carbon dioxide, methane, nitrous oxide, industrial gases, water vapor and ozone. The composition of these gases making up the atmosphere blanketing Earth creates something called the greenhouse effect. The sun radiates solar energy towards the Earth, the surface of the Earth radiates heat energy outwards. Some of this heat radiation passes all the way back out through the atmosphere but some is absorbed and re-emitted by greenhouse gases. This cycle is known as the greenhouse effect and is responsible for maintaining the temperature of the Earth. Without the atmosphere, the Earth would not be able to sustain life because it would be far too cold.[24] As previously mentioned, nature has a system for cycling this energy from the sun that allows for habitable conditions. However, humans add to this natural amount of CO_2 in the atmosphere when they burn fossil fuels. There are other greenhouse gas emissions that contribute to the rise in greenhouse gases, but “in 2016, fossil fuels were the source of about 76% of total U.S. human-caused greenhouse gas emissions”, so I will continue to focus on that cause.[25]

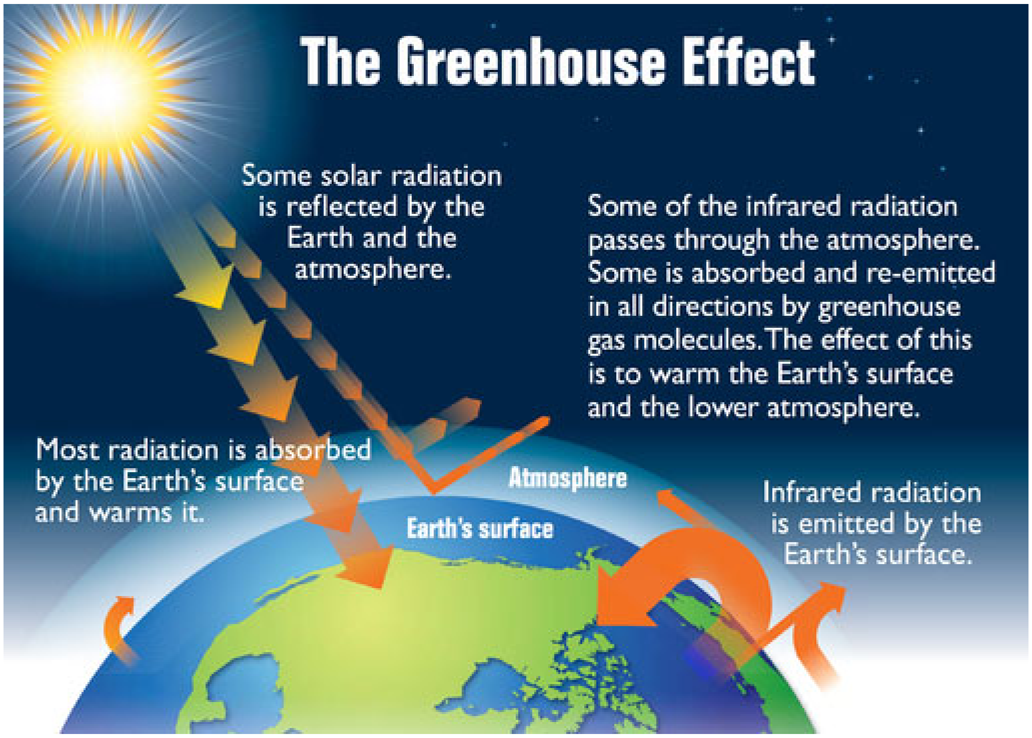

Figure 2. A diagram that explains the stages of the Greenhouse Effect. Source: "The Greenhouse Effect" in: "Introduction," in: US EPA (December 2012) Climate Change Indicators in the United States, 2nd edition, Washington, DC, USA: US EPA, p.3. EPA 430-R-12-004.

Human Activity and Environmental Consequences

This increased amount of CO_2 is almost inarguably what is contributing to climate change. The danger in changing the climate over time is that is has strong effects on weather, which has more immediate consequences for current society. Success of past civilizations depended on the resources provided by nature and the use that humans created for them. The innovation that has come from humans constantly developing new technology from Earth's resources is undeniably extraordinary. However, this innovation is not without a cost to the environment itself. We refer to nonrenewable resources as "nonrenewable" because they will eventually become finite, even if it's not within our lifetime. The rate at which humans consume these resources has the most impact on climate. Climate and weather are related but not interchangeable. Weather refers to the day-to-day conditions of the atmosphere, whereas climate refers to a range of a region's weather. The cause behind the changes in weather and climate stem from the sun's heat and light energy that is emitted. As the heat from the surface of the Earth heats the atmosphere above it, it "leads to the development of a dynamic mix of water and gases at various temperatures and densities in the atmosphere that move around constantly, creating weather phenomena that are constantly changing yet relatively predictable."[26] Climate change is most exemplified through more extreme weather events like droughts or intense precipitation. As the increased levels of CO_2 enter and remain in the atmosphere trapping heat, it results in changing the way the atmosphere absorbs and transports the energy over long distances, while also altering the water cycle. In addition, the increased energy can cause the polar ice sheets to melt which results in a rise in sea level and less reflectivity from the Earth's surface again inciting another change in the energy balance between the sun and the surface of the Earth. Lastly, another impact to consider is the heat capacity of water. Water has a much higher heat capacity than air and therefore will also trap heat much more easily warming the ocean and affecting the ocean currents.

Reducing the Impact of Human Activities on the Environment

One obvious way to reduce the impact of human activities on the environment is to begin switching our energy sources to renewable energies. From my research, in order to provide the world with enough energy I think the best course of action would be to use a mixture of many types of renewable energy dependent on region. Our world regions can be vastly different from one another, so it makes sense that we should adapt our energy sources to what is most abundant and available in that region. In a study completed by a Stanford engineer, Mark Jacobson, he proposed a state-by-state plan to achieve 100% renewable energy by 2050. It is possible! He listed the biggest challenges to his plan or any plan for a renewable energy transition as social and political barriers.[27]

There are some examples of major cities around the world that have considered their environmental impact and they have begun to make changes to reduce those impacts. Some examples of what cities are doing to combat carbon emissions include:

- Berlin is phasing out coal use.
- Copenhagen is developing 100 MW of wind power and electrifying their bus fleet.
- New York City is continuously implementing more solar power.
- Rio de Janeiro built a ten-mile metro line and added more bus transit lines.
- Washington D.C. designed a Green Bank to finance local renewable and energy-efficient projects.[28]

These are just small changes that cities are implementing to begin moving toward a carbon-free future. Ultimately it is up to cities to consider, update and implement new energy policies.

Another way to combat carbon emissions is carbon sequestration, which is a way to capture CO_2 from the air and store it. There are two types of carbon sequestration: biologic and geologic. In geologic carbon sequestration, carbon dioxide is captured from stationary sources, like a power plant. The captured gas is compressed until it takes on a liquid state and injected underground into porous rocks.[29] In biological sequestration, storage in wood by reforestation or in microalgae that utilize the CO_2 captured from flue gases and controlled light to carry out photosynthesis to produce biomass.

A Closer Look at Chicago's Energy

The Statistics

According to the American Lung Association, Chicago ranked as the 19th most polluted city in the United States.[30] 91% of Chicago's emissions came from electricity, natural gas and transportation. "Without mitigation, Chicago's emissions of 12 tons of carbon dioxide equivalent per capita in 2000 would be expected to grow 35 percent by 2050."[31]

Assessment

As with any region, there are many effects that global climate change can have on Chicago. The National Climate Assessment listed six key effects carbon emissions and increasing temperatures will have on the Midwest region. Among the effects are impacts on agriculture, forest composition, public health, fossil-fuel dependent electricity system, rainfall and flooding, and the health of the Great Lakes.

Temperature

If emissions conditions stay the same, Chicago is projected to increase two degrees Fahrenheit in annual average temperature. This would also play a role in lengthening the growing season for agriculture and reduce the number of extremely cold days by 30%. On the other hand, there would also be an increase in extreme heat days, which are days over 90 degrees Fahrenheit. This would be linked to a higher frequency of heat waves, which can mean several every year if high carbon emissions hold. More heat waves could potentially mean more deaths.[32]

Air Quality

"As temperatures warm and atmospheric circulation patterns change, bringing oppressive summer weather patterns to Chicago earlier in the year and making them last longer, ground-level ozone and particulate matter concentrations are projected to rise." There is an expected increase in the concentration of ground level ozone anywhere from 10-25% depending on the level of carbon emissions. High carbon emissions would mean higher ozone levels. Increased ozone could mean increased health issues in addition to ecosystem and agricultural instability.[33]

Public Health

Increased ground level ozone could mean increased health issues, especially for those people with asthma and other respiratory illnesses. "Breathing ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. It can worsen bronchitis, emphysema, and asthma. "Bad" ozone also can reduce lung function and inflame the linings of the lungs. Repeated exposure may permanently scar lung tissue."[34] Increased health issues without proper access to healthcare can lead to more morbidity.

Precipitation

Increased carbon emissions projects increased precipitation in the winter and spring. Increased precipitation can pose significant flood risks depending on infrastructure. It is noted that Chicago has experienced flooding in the past with rains totaling 2.5 inches in a 24 hour period and continuing to increase carbon emissions will increase the frequency of heavy rain periods. As far as winter precipitation, since temperatures would be expected to warm, this would mean less snowfall or decreased snow cover.[35]

Chicago Climate Action Plan

As a result of the research on Chicago's impact on carbon emission, Mayor Richard M. Daley designed a task force to tackle and propose a plan to reduce Chicago's carbon emissions in 2008. The goal of the Chicago Climate Action Plan is to reduce greenhouse gas emissions by 80% from the 1990 level by 2050. The task force developed the Chicago Climate Action Plan, one of the first organized plans for a major city in the U.S. In the plan were five strategies proposed to lead Chicago to an overall reduced greenhouse gas emissions level. The first strategy is to reduce energy use in all building by retrofitting existing buildings. Retrofitting could include improving insulations, installing energy efficient windows or installing high efficiency furnaces and boilers. The second strategy is to implement clean and renewable energy sources. Chicago has the potential to replace existing energy sources with photovoltaic and wind energy. The third strategy is improving transportation options. This strategy includes investing in transit incentives, expanding clean transit options, improving fleet efficiency, switching to cleaner fuels, etc. The fourth strategy is reduced waste and industrial pollution. This would mean revamping the recycling system and encouraging citizens to reduce, reuse and recycle. The last and fifth strategy is adaptation. This strategy includes managing urban heat islands, protecting air quality and managing storm water. Within each of these strategies there are proposed actions that are suggested at both the industrial and residential levels. It is believed that implementation of these strategies can reduce greenhouse gas emissions over time and if not taken the effects could be dire.[36]

Teaching Strategies

Each year I receive a diverse population of academic abilities in my classroom. In order to meet the needs of all students, I utilize a variety of different strategies to address different learning styles and academic needs. One key strategy my department implements throughout all of our units is what is referred to as a Key Concept Tracker, which essentially becomes a student-developed reference sheet of scientific principles. It is a paper document that students store in the classroom and revisit after each investigation or lesson. The document is broken down into questions we aim to answer generalized as scientific principles we learn from evidence gathered during our investigations. This tool also allows me to differentiate instruction because students independently answer the investigation questions based on their understanding at the culmination of each lesson and each student receives individual feedback before proceeding to record their response on their tracker. Based on responses, I can plan to reteach the whole class or pull a small group while simultaneously providing extension activities to push students' critical thinking for those that have mastered the principle. In the event that I reteach a concept in a new format or I pull a small group, students answer the question again and receive feedback and this cycle continues until students have mastered the concept and proceed to record it as a scientific principle.

Another strategy I will use throughout the unit is structured notes. Since this will be the first unit I teach in my sequence of units across the year, I structure notes so that students record and keep track of useful information that we cover in each lesson and investigation. The type of lesson we are conducting determines the content that is recorded. For example, notes related to an informational text might ask students to interpret quotes from the text, or ask students to go back in the text to find evidence that supports our investigation question. Whereas, notes for a hands-on investigation or simulation might ask students to record data, analyze the data and then interpret the data with guided questions.

Other strategies that are implemented throughout different lessons are science seminars in which students discuss their findings. This strategy complements inquiry based lessons because it allows for students to come together to discuss their data and come to consensus about the principles they uncover in different lessons. In a science seminar, we introduce a focus question. Typically, the question is our investigation question for whatever lesson we are discussing. Students have already been presented with multiple claims, or they generate their own claims. Once they present the claim they are defending, they provide evidence and reasoning as they debate against other claims. In the event that they all support the same or a similar claim, they debate which evidence most strongly supports the claim. The seminar can be run in a fishbowl style, where some students participate in the discussion and the rest observe and track the discussion. Or, all students can be a part of the seminar, which is most easily done by still keeping discussion group small but running multiple rounds of the discussion. If all students participate, I still have students who are observing and tracking the discussion. Items that students track could be pieces of evidence, logical reasoning, specific sentence stems, participation, etc.

Students will also take part in a variety of lessons to appeal to their different learning styles like hands-on activities, informational text readings, simulations and labs. This allows for students to engage in lessons to learn and experience the same principles in multiple formats.

Teaching Activities

To introduce students to the different types of energy, they will perform a series of investigations by observing simple physical systems. Students begin to define energy by defining whether each system they interact with has energy or not based on their own conceptions of what they think energy is. Once students are introduced to vocabulary, like kinetic energy and potential energy, they will be able to justify or revise their original thinking of the systems. They will also read a leveled informational text about what energy is, which will reinforce the definition. The article will also give students their first introduction to sources of energy like wind and solar energy.

The next section of the unit will require students to investigate sources of energy and energy transformation. During this section, students will conduct research of renewable and nonrenewable resources. They will specifically research individual energy sources, how each harnesses energy to transform into something usable for humankind and the consequences behind utilizing different sources. They will participate in a debate defending and arguing for their energy source to be chosen for future energy use. In addition to the research, students will engineer windmills to deepen their understanding of energy conversion. This will also complement their research of energy sources since windmills are one example of an energy source. Students' goal will be to engineer a windmill that produces the most electricity. We will use the Alternative Energy resources provided by Boeing in partnership with the Teaching Channel to guide the engineering process of designing the best turbine blade to produce the highest electrical energy output.

The penultimate section of the unit will ask students to investigate carbon emissions and the effect it has on the environment. Students will utilize a simulation from the website of PhET Interactive Simulations, which will allow them to manipulate different carbon emission scenarios and collect data around global temperature. They will research the effect that rising global temperatures has on daily life and how to combat carbon emissions.

The final section of the unit will end with students assessing Chicago's carbon footprint and energy usage. Students will research Chicago's current energy statistics and energy initiatives implemented by the city. They will finish by choosing to propose a new proposal to improve or regulate Chicago's carbon emissions or revise an existing initiative while also providing a strategy to better implement that initiative around the city.

Appendix on Implementing District Standards

In the *Next Generation Science Standards* (*NGSS*), there are three dimensions that address the desired Performance Expectations, which include Disciplinary Core Ideas, Science & Engineering Practices and Crosscutting Concepts. The disciplinary core idea (DCI) that is at the center of focus for this unit is energy. The first core idea is PS3.A: Definitions of Energy. Energy is a difficult term to define but is most commonly referred to as “the ability to cause change”. In keeping the *NGSS* in mind though, defining energy is best achieved by describing how energy behaves. For example, kinetic energy is associated with motion and can be quantified with an equation that relates kinetic energy being proportional to the mass of an object and the square of its velocity. Potential energy is proportionally related to an object’s mass, gravity and height above some reference point. By the end of 8th grade, students understand and identify that speed determines whether an object has kinetic energy and recognize that potential energy is “associated with the distance between two mutually attracting masses” (Duncan et al. 2017). In addition to defining energy’s behavior as kinetic or potential energy, students should be able to identify qualitative descriptions of how energy is manifested in different phenomena and explain energy transfer and conversion. This DCI most closely aligns with the Performance Expectations MS-PS3-1 and MS-PS3-2.

The second core idea is PS3.B: Conservation of Energy and Energy Transfer. Energy remains the same in an isolated system according to the law of conservation of energy. However, most experiences students have involve open systems in which energy transfer occurs. The expectations of eighth grade students in the *NGSS* are that students should be able to qualitatively describe energy transfers between systems. Specifically, students should recognize that as the energy of one system decreases, the energy of a relevant system increases, thus exemplifying energy conservation. This DCI most closely aligns with the Performance Expectation MS-PS3-5.

In addition to the disciplinary core idea of energy, a second complementary core idea is brought to the forefront in this unit related to humans’ use of energy and its impact on the environment. The second core idea is Earth and Human Activity. There are two component ideas that will be touched upon by this unit which are ESS3.C: Human Impacts on Earth’s Systems and ESS3.D: Global Climate Change. By incorporating these two ideas the unit will allow for students to consider the role that they as individuals have on climate change and also how their own city plays a role in emissions. By building their understanding of energy transfer, students can then consider renewable and nonrenewable energy sources and how to best mitigate the effects of different kinds of pollution (Duncan et. al 2017). This DCI most closely aligns with the Performance Expectations MS-ESS-3, MS-ESS3-4 and MS-ESS3-5.

Teacher Resources

“The Boy Who Harnessed the Wind”, by W. Kamkwamba and Bryan Mealer

“Understanding Climate Change”, by Laura Tucker and Lois Sherwood

Choosing Earth’s Climate Future (NOVA Education):

https://www.pbs.org/wgbh/nova/article/how-are-we-preparing-students-earths-climate-future/

Toolbox for Teaching Climate and Energy:

https://www.climate.gov/teaching/toolbox-teaching-climate-energy

PhET Simulations:

https://phet.colorado.edu/en/simulation/legacy/greenhouse

Boeing and Teaching Channel Partnership:

https://www.teachingchannel.org/wind-energy-engineering-unit-boeing

Energy Resources from the National Science Teaching Association:

https://ngss.nsta.org/classroom-resources-results.aspx?CoreIdea=3

Earth and Space Resources from National Science Teaching Association:

https://ngss.nsta.org/classroom-resources-results.aspx?CoreIdea=11

Generation Genius:

http://www.generationgenius.com

NOAA Climate Teaching Resources:

https://www.climate.gov/teaching

Bibliography

Bernstein, Scott, Tim Lang, Jill Siegal, Ruth Klotz-Chamberlain, Emily Metz, Anette Stahelin, Nicole Gotthelf, Katherine Nichols, and Kathryn Tholin. *Chicago's Greenhouse Gas Emissions.* Report. 2008. Accessed July 15, 2019. https://www.elevateenergy.org/wp/wp-content/uploads/2014/01/Chicagos_Greenhouse_Gas_Emissions.pdf.

Biello, David. "How Wind Turbines Affect Your (Very) Local Weather." Scientific American. October 04, 2010. Accessed July 14, 2019. https://www.scientificamerican.com/article/how-wind-turbines-affect-temperature/.

Brainerd, Jean. "Combustion Reaction." CK-12. November 01, 2012. Accessed July 15, 2019. https://www.ck12.org/c/physical-science/combustion-reaction/lesson/Combustion-Reactions-MS-PS/.

Chicago Climate Action Plan. PDF. Chicago: Chicago Climate Task Force, 2008.

Cook, John, Dana Nuccitelli, Sarah A. Green, Mark Richardson, Barbel Winkler, Rob Painting, Robert Way, Peter Jacobs, and Andrew Skuce. "Quantifying the Consensus on Anthropogenic Global Warming in the Scientific Literature." *Environmental Research Letters* 8, no. 2 (May 15, 2013). doi:10.1088/1748-9326/8/2/024024.

Dhar, Michael. "How Do Solar Panels Work?" LiveScience. December 06, 2017. Accessed July 16, 2019. https://www.livescience.com/41995-how-do-solar-panels-work.html.

Duncan, Douglas W., and Eric A. Morrissey. The Concept of Geologic Carbon Sequestration. PDF. Virginia: U.S. Geological Survey, March 2011.

Duncan, Ravit Golan, Joseph S. Krajcik, and Ann E. Rivet. *Disciplinary Core Ideas: Reshaping Teaching and Learning*. Arlington, VA:

National Science Teachers Association, 2017.

"Electricity in the United States." Electricity in the United States - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration. Accessed June 15, 2019. https://www.eia.gov/energyexplained/index.php?page=electricity_in_the_united_states.

Farrelly, Damien J., Colm D. Everard, Colette C. Fagan, and Kevin P. McDonnell. "Carbon Sequestration and the Role of Biological Carbon Mitigation: A Review." *Renewable and Sustainable Energy Reviews* 21 (February 21, 2013): 712-27. doi:10.1016/j.rser.2012.12.038.

"Global Carbon Dioxide Growth in 2018 Reached 4th Highest on Record." Global Carbon Dioxide Growth in 2018 Reached 4th Highest on Record | National Oceanic and Atmospheric Administration. Accessed July 16, 2019. https://www.noaa.gov/news/global-carbon-dioxide-growth-in-2018-reached-4th-highest-on-record.

"How Do Wind Turbines Work?" Energy.gov. Accessed July 16, 2019. https://www.energy.gov/eere/wind/how-do-wind-turbines-work.

"How Does a Steam Turbine Work?" Petrotech, Inc. Accessed July 16, 2019. https://petrotechinc.com/how-does-a-steam-turbine-work/.

"How Does "Bad" Ozone Affect Human Health and the Environment?" How Does "Bad" Ozone Affect Human Health and the Environment? – Rabbit Air. 2012. Accessed July 15, 2019. https://www.rabbitair.com/pages/how-does-bad-ozone-affect-human-health-and-the-environment.

Jackson, Clare. "What Happens When Hydrogen & Oxygen Combine?" Sciencing. March 02, 2019. Accessed July 16, 2019. https://sciencing.com/happens-hydrogen-oxygen-combine-8515474.html.

J.M.K.C. Donev et al. (2019). Energy Education - Coal formation [Online]. Available: https://energyeducation.ca/encyclopedia/Coal_formation. Accessed: July 14, 2019.

J.M.K.C. Donev et al. (2019). Energy Education - Coal formation [Online]. Available: https://energyeducation.ca/encyclopedia/Coal_formation. Accessed: July 14, 2019.

J.M.K.C. Donev et al. (2019). Energy Education - Oil formation [Online]. Available: https://energyeducation.ca/encyclopedia/Oil_formation. Accessed: July 14, 2019.

MacKay, David J. C. *Sustainable Energy - without the Hot Air*. Cambridge: UIT Cambridge, 2013.

"Most Polluted Cities: State of the Air." American Lung Association. Accessed July 13, 2019. https://www.lung.org/our-initiatives/healthy-air/sota/city-rankings/most-polluted-cities.html.

"Next Generation Science Standards." Next Generation Science Standards. May 14, 2019. Accessed June 15, 2019. https://www.nextgenscience.org/.

Normile, Dennis. "Round and Round: A Guide to the Carbon Cycle." *Science* 325, no. 5948 (September 24, 2009): 1642-643. doi:10.1126/science.325_1642.

"Overview of Greenhouse Gases." EPA. April 11, 2019. Accessed June 15, 2019. https://www.epa.gov/ghgemissions/overview-greenhouse-gases.

Petro Industry News. "How Is Natural Gas Converted into Energy?" Petro Online. November 07, 2014. Accessed July 14, 2019.

https://www.petro-online.com/news/fuel-for-thought/13/breaking-news/how-is-natural-gas-converted-into-energy/32371.

Plastrik, Peter, and John Cleveland. *Life after Carbon: The next Global Transformation of Cities*. Washington D.C.: Island Press, 2018.

Riebeek, Holli. "The Carbon Cycle." NASA. June 16, 2011. Accessed July 13, 2019. https://earthobservatory.nasa.gov/features/CarbonCycle.

Schwarz, Christina V., Cindy Passmore, and Brian J. Reiser. *Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices*. Arlington, VA: NSTA Press, National Science Teachers Association, 2017.

Stanford University. "Stanford Engineers Develop State-by-state Plan to Convert U.S. to Clean, Renewable Energy." Stanford Engineers Develop State-by-state Plan to Convert U.S. to 100% Clean, Renewable Energy by 2050. April 09, 2016. Accessed July 15, 2019. https://news.stanford.edu/2015/06/08/50states-renewable-energy-060815/.

U.S. Energy Facts - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration. Accessed June 15, 2019. https://www.eia.gov/energyexplained/index.php.

Willard, Ted. *The NSTA Quick-reference Guide to the NGSS, K-12.*Arlington, VA: NSTA Press, National Science Teachers Association, 2015.

Wuebbles, Donald J., Katharine Hayhoe, and Julia Parzen. "Introduction: Assessing the Effects of Climate Change on Chicago and the Great Lakes." *Journal of Great Lakes Research* 36 (July 1, 2010): 1-6. doi:10.1016/j.jglr.2009.09.009.

Yergin, Daniel. *The Quest: Energy, Security and the Remaking of the Modern World*. New York, NY: Penguin Books, 2012.

Endnotes

---

1. Chicago Climate Action Plan, 2008; pp. 5-6
2. Cook et al, 2013, p. 1
3. Duncan et. al, 2017, p. 55
4. Jackson, Clare. "What Happens When Hydrogen & Oxygen Combine?" Sciencing. March 02, 2019. Accessed July 16, 2019. https://sciencing.com/happens-hydrogen-oxygen-combine-8515474.html.
5. "How Does a Steam Turbine Work?" Petrotech, Inc. Accessed July 16, 2019. https://petrotechinc.com/how-does-a-steam-turbine-work/.
6. J.M.K.C. Donev et al. (2019). Energy Education - Oil formation [Online]. Available: https://energyeducation.ca/encyclopedia/Oil_formation. (accessed July 14, 2019).
7. U.S. Energy Information Administration, 2018
8. J.M.K.C. Donev et al. (2019). Energy Education - Natural gas formation [Online]. Available: https://energyeducation.ca/encyclopedia/Natural_gas_formation. (accessed July 14, 2019).
9. Petro Industry News. "How Is Natural Gas Converted into Energy?" Petro Online. November 07, 2014. Accessed July 14, 2019. https://www.petro-online.com/news/fuel-for-thought/13/breaking-news/how-is-natural-gas-converted-into-energy/32371.
10. J.M.K.C. Donev et al. (2019). Energy Education - Coal formation [Online]. Available: https://energyeducation.ca/encyclopedia/Coal_formation. (accessed July 14, 2019).
11. U.S. Energy Information Administration, 2018
12. U.S. Energy Information Administration, 2018

13. Lewis, 2007, p. 11
14. Dhar, Michael. "How Do Solar Panels Work?" LiveScience. December 06, 2017. Accessed July 16, 2019. https://www.livescience.com/41995-how-do-solar-panels-work.html.
15. Lewis, 2007, p. 9
16. David Biello, "How Wind Turbines Affect Your (Very) Local Weather," Scientific American, October 04, 2010, accessed July 14, 2019, https://www.scientificamerican.com/article/how-wind-turbines-affect-temperature/.
17. "How Do Wind Turbines Work?" Energy.gov. Accessed July 16, 2019. https://www.energy.gov/eere/wind/how-do-wind-turbines-work.
18. Yergin, 2012, p. 426
19. Jean Brainerd, Combustion Reaction, https://www.ck12.org/c/physical-science/combustion-reaction/lesson/Combustion-Reactions-MS-PS/, (accessed July 12, 2019)
20. Holli Riebeek, "The Carbon Cycle," NASA, June 16, 2011, accessed July 13, 2019, https://earthobservatory.nasa.gov/features/CarbonCycle.
21. MacKay, 2013, p. 6
22. "Global Carbon Dioxide Growth in 2018 Reached 4th Highest on Record." Global Carbon Dioxide Growth in 2018 Reached 4th Highest on Record | National Oceanic and Atmospheric Administration. Accessed July 16, 2019. https://www.noaa.gov/news/global-carbon-dioxide-growth-in-2018-reached-4th-highest-on-record.
23. Yergin, 2012, pp. 443-447
24. Duncan et. al, 2017, pp. 212-213
25. U.S. Energy Information Administration, 2018
26. Duncan et. al, 2017, p. 211
27. Stanford University. "Stanford Engineers Develop State-by-state Plan to Convert U.S. to Clean, Renewable Energy." Stanford Engineers Develop State-by-state Plan to Convert U.S. to 100% Clean, Renewable Energy by 2050. April 09, 2016. Accessed July 15, 2019. https://news.stanford.edu/2015/06/08/50states-renewable-energy-060815/.
28. Plastrik, 2018, pp. 32-33
29. Douglas W. Duncan and Eric A. Morrissey, *The Concept of Geologic Carbon Sequestration*, PDF, Virginia: U.S. Geological Survey, March 2011.
30. "Most Polluted Cities: State of the Air." American Lung Association. Accessed July 13, 2019. https://www.lung.org/our-initiatives/healthy-air/sota/city-rankings/most-polluted-cities.html.
31. Bernstein et al., 2008, p. 4
32. Wuebbles, Donald J., Katharine Hayhoe, and Julia Parzen. "Introduction: Assessing the Effects of Climate Change on Chicago and the Great Lakes." *Journal of Great Lakes Research* 36 (July 1, 2010): 1-6. doi:10.1016/j.jglr.2009.09.009.
33. Wuebbles, Donald J., Katharine Hayhoe, and Julia Parzen. "Introduction: Assessing the Effects of Climate Change on Chicago and the Great Lakes." *Journal of Great Lakes Research* 36 (July 1, 2010): 1-6. doi:10.1016/j.jglr.2009.09.009.
34. "How Does "Bad" Ozone Affect Human Health and the Environment?" How Does "Bad" Ozone Affect Human Health and the Environment? – Rabbit Air, 2012, , accessed July 15, 2019, https://www.rabbitair.com/pages/how-does-bad-ozone-affect-human-health-and-the-environment.
35. Wuebbles, Donald J., Katharine Hayhoe, and Julia Parzen. "Introduction: Assessing the Effects of Climate Change on Chicago and the Great Lakes." *Journal of Great Lakes Research* 36 (July 1, 2010): 1-6. doi:10.1016/j.jglr.2009.09.009.
36. *Chicago Climate Action Plan.* PDF. Chicago: Chicago Climate Task Force, 2008.