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The Carbon Cycle and the Connection to Human Activity

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I teach General Science and AP Biology in an urban magnet high school. This is a performing arts magnet school, located in the city of New Haven, CT. Being a magnet school we draw 30% of our students from surrounding districts that are a mix of urban and suburban school systems. In general our students perform well academically due to their desire to be in this school to study their chosen art. We utilize a block schedule with four 90 minute periods a day. A day will be either even or odd, resulting in any given class occurring every other day for our students. The students study their art every day, with 2 blocks scheduled for art instruction.

This unit has been produced for general science, also known as physical chemistry in this district. This is a mandatory class for all freshmen and is an introduction for them to chemistry through the lens of environmental science. For example, we teach units on acid rain, rather than just acids and bases.

Content Objectives

The focus of this unit is on the cycling of carbon on this planet. This unit will cover all of the major and minor stores of carbon, called reservoirs or sinks. This unit will also cover the processes that move carbon from store to store. The third layer to understanding and teaching about the carbon cycle is to address the numbers. I will provide the most up to date and accurate estimates of the amount of carbon in each reservoir as well as the rate of carbon release and uptake occurring yearly on Earth. Both naturally occurring and anthropogenic activities will be considered.

Teaching Strategies

Content is covered through reading, lecture, and discussion. The understanding of the content is fostered by activities that require collaboration, modeling, and justification. It is necessary to first instruct students about the carbon cycle before engaging them in activities related to the understanding of how human activity is affecting carbon flow.

Carbon Reservoirs

Carbon is sequestered in several different reservoirs. The reservoirs vary in size (total volume of carbon) and relative sequester time period (how long any given carbon atom is maintained in the reservoir). I find that the easiest organization of stores is into four categories: Earth's crust, oceans, the atmosphere, and terrestrial ecosystems. These stores will be further divided into smaller categories. The amount of carbon in each of these reservoirs is given in gigatonnes (GT) with numbers acquired from NASA. A gigatonne is equal to 1 x 10^{12} kilograms. These numbers are recent estimates of the mass of carbon but are not exact. Nonetheless the numbers are useful when comparing one reservoir to another when comparing reservoirs.

Carbon reservoirs are defined as being long and short term. Long term carbon stores find carbon being held for lengths of time on the order of millions to hundreds of millions of years. When defining a carbon reservoir as being short term the time period of sequestration is on the order of years to hundreds of years. In order to grasp the scope of the carbon cycle, and ultimately man's impact on it, it is important to note the approximate holding periods of carbon as it passes through reservoirs. The impact of man on the carbon cycle, as long term stores are being manipulated by current activities, is now a necessary component of understanding the cycle as a whole.

The processes that move carbon from reservoir to reservoir will be discussed in a subsequent section. This section will define the reservoirs and discuss current estimates of the mass of carbon contained in each as well as discussing the relative amount of time any given carbon atom is expected to spend in the store.

Carbon Reservoirs: The Earth's Crust

This reservoir encompasses sedimentary rocks and hydrocarbons. It is estimated that the mass of carbon in this store is roughly 100,000,000GT. Limestone and shale are the sedimentary rocks that amass a significant portion of this store, approximately 99.996%. Hydrocarbons such as petroleum, natural gas, and coal account for the remaining portion. These two groups are considered separately because of their different uses to man.

Limestone is a chalky, white rock and shale is typically a dark brown to red or black color. Both are relatively soft as is the nature with sedimentary rocks. Sedimentary rocks are formed as layers of material are piled on top of each other over the years. As they are buried by still more layers of sediment they are compacted by pressure of the subsequent layers. Over the course of millions of years and just as many layers of sediment the material is compacted into rock.

Limestone is primarily composed of calcium carbonate deposits that are the remains of shell forming organisms and corals. Innumerous amounts of ocean dwelling creatures form shells by combining carbon and calcium. When these organisms die their remains drift to the bottom of the ocean and this carbon source is deposited. These deposition layers, of organic source calcium carbonate, are lithified into limestone. Limestone forming events occur primarily in shallow warm seas, where the conditions for the necessary organisms are best. These shallow sea environments are found in shallow between 30 degrees north latitude and 30 degrees south latitude. Areas of importance today are the Caribbean Sea, Indian Ocean, Persian Gulf, Gulf of Mexico, around Pacific Ocean Islands and within the Indonesian archipelago.

Limestone is a general term for sedimentary rock composed primarily of calcium carbonate and thus limestone has many forms. Tufa, chalk, coquina, fossiliferous limestone, lithographic, travertine, and oolitic limestone are all common forms of limestone.

Carbon trapped in limestone is subjected to release when the limestone has been exposed to the surface. Rain, which is naturally acidic, weathers these rocks releasing the carbon back into the environment. This process will be discussed in subsequent sections of this unit. A significant point of discussion is the use of limestone across the globe. Ultimately the use of limestone as a commercial commodity results in the movement of carbon from the reservoir wherein it will find its way back into the cycle. Limestone is used a dimension stone in construction for such items as tiles and sills to structural blocks or even statues. Asphalt shingles are embedded with crushed limestone as it acts as an effective weather and heat resistant layer to the shingle. Limestone, along with shale and sand, is the key ingredient in Portland cement. The metal refining industry uses limestone as a flux. Aglime is used to reduce the acidity of soils worldwide, as well is lime. Limestone is found in animal feed as an easy form of calcium supplement for chickens, to form strong eggs, and dairy cows, for milk production.

Shale is formed from the deposition of organic matter that has been covered and mixed with mud and silt. As is the process with other sedimentary rocks layers accumulate over eons and combined with pressure and other tectonic forces the rock is formed. Shale is used to produce clays and common building materials such as brick and cement. Recent discoveries of hydrocarbons with shale have diversified the importance of shale in the overall carbon cycle discussion. We now extract natural gas from shale through hydraulic fracturing (hydrofracking).

Certain shale deposits have high amounts of natural gas trapped within them in tiny pores. Although this was known about for years, it was not until the 1990’s that drilling companies developed an effective method of liberating the hydrocarbon. Essentially they drill down to the shale and then pump down water at high pressure to fracture the rock and allow the gas to flow out into the well. The natural gas that is trapped in shale shows an effective connection between the two reservoirs of carbon and why it is responsible to consider the Earth’s crust as single reservoir and simplify discussions in the classroom.

The latest estimate for the amount of carbon in hydrocarbons within the Earth’s crust is 4,000GT. Hydrocarbons, also called fossil fuels, are the product of ancient organic matter that was trapped underground and subjected to intense pressure and temperatures. The intent of this unit is to discuss the movement for carbon from a hydrocarbon to another reservoir, mainly the atmosphere, and not to address the world of controversy surrounding the extraction, control, and use of hydrocarbons across the globe. This unit will approach the math for calculating the amount of carbon that is moving from hydrocarbons to the atmosphere as it is important for students to realize that the amounts are quantifiable. By sharing these calculations with students the connection between energy use and their impact becomes more salient.

Carbon Reservoirs: Oceans

This reservoir includes all of the world's ocean water and flora and fauna living within. Discussing the ocean as a reservoir requires that ocean surface, or epipelagic zone, and all depths below are considered separately. Depths below the epipelagic will be referred to as “deep ocean” within this unit. Note that there are several layers or zones, but differentiating factor is light penetration. Light penetration is limited to the epipelagic. The best estimate for total carbon in the ocean is 39,000GT, with 38,000GT of that in the waters of the deep ocean. The epipelagic zone contains the remaining balance of carbon in the ocean, accounting for the biota that live in the ocean, primarily in this zone of water. Thus the majority of carbon found in the ocean is bonded within inorganic carbon molecules. A small portion is dissolved carbon dioxide and carbon that is being used in organic molecules mostly limited to the epipelagic zone.

The ocean surface, or epipelagic zone, extends about 200 meters in depth. Sunlight penetrates this zone supporting a rich array of life. The ocean’s primary producers, phytoplankton up and through to the apex consumers live within this zone. The enormity of the ocean is hard to substantiate and it is fascinating that the majority of all oceanic life is found in just the top 200 meters, considering that the average ocean depth is around 3700 meters, with a maximum depth of 11,000 meters.

The carbon accounted for in the epipelagic zone, just about 3% of the carbon in this reservoir, the oceans, is significant to the carbon cycle because of its role in short term carbon cycling. This carbon is bound in either organic molecules or as inorganic carbon dioxide. The biota of this zone is utilizing carbon for growth and maintenance. This biological carbon is then released through death and decay. The flora of the ocean utilizes dissolved carbon dioxide to drive photosynthesis producing carbohydrates. Plants and algae are consumed and the carbohydrates are metabolized being incorporated into proteins and other biological molecules and being released back into the water through respiration. Consider all of the fish, coral, crustaceans, mammals, plants, and algae utilizing, either directly or indirectly, the dissolved carbon dioxide to drive life. The inorganic component of this this faction is in the form of dissolved carbon dioxide. Carbon dioxide reacts with ocean water to form carbonic acid and bicarbonate. Bicarbonates are used by plants and animals to form calcium carbonate shells. This calcium carbonate will often find its way to the bottom of ocean where it will deposit and eventually move to another reservoir, the earth’s crust, as limestone.

The deep ocean, for the purposes of this unit, accounts for the other 97% of carbon found in this reservoir. Here carbon is found bound in organic molecules such as carbonic acid and bicarbonates. The majority is found in bicarbonates. Another point of separation between deep ocean and ocean surface, in addition to sunlight penetration, is the relative time that carbon can spend in the reservoir. The ocean surface is a short term reservoir and carbon is cycling in and out of the ocean surface rapidly. The deep ocean is a long term reservoir wherein carbon can be stored for thousands to millions of years.

Carbon Reservoirs: Atmosphere

There is just 750GT of carbon in the atmosphere. Though this number is low compared to the massive store in the Earth’s crust and the oceans, it is of significant importance to human activity. The carbon molecule of interest in this store is carbon dioxide which accounts for the bulk of carbon in the atmosphere. The remaining balance of atmospheric carbon is in molecules of methane and other molecules. The amount of carbon dioxide in the atmosphere is believed to have an influence on global climate. Though the debate is ongoing as to the effect of carbon dioxide on climate, there is solid evidence that global atmospheric carbon has risen 34% over the past few hundred years. Atmospheric carbon is bound in carbon dioxide primarily. Less significant amounts are accounted for in methane and various other molecules. The atmosphere is a short term store of carbon, with carbon cycling in and out of the atmosphere relatively rapidly, on the order of years, months, and days.

Atmospheric carbon is being released and sequestered through biological processes and physical processes. Photosynthesis by terrestrial plants is sequestering carbon dioxide which subsequently liberated through respiration and decay. Physical processes release carbon through weathering of rocks and gas exchange on the ocean's surface. Subsequently carbon is sequestered from the atmosphere via gas exchange, photosynthesis, and deposition.

Carbon Reservoirs: Terrestrial Ecosystems

This reservoir encompasses soil and land plants and totals to approximately 2100GT. Included in this store are all the terrestrial animals as well, though their total mass of carbon is insignificant compared to the plants and soil. This carbon is primarily found in organic molecules. Carbon is fundamental to every living thing. This is the carbon making up every plant, animal, and microorganism. Organic molecules found in living, dead, and decaying organic matter.

The soils hold the bulk of the carbon in this reservoir accounting for roughly 75%. Carbon is processed in the soil by microbes which through decomposition release the carbon back to the atmosphere as carbon dioxide. On land woody plants are the most significant players in this store because of their ability to store enormous amounts of carbon in the cellulose that they are comprised of.

Carbon Exchange

The carbon cycle can be broken down into two categories, short term and long term. The short term cycle far exceeds the long term cycle in mass of carbon movement annually. Consider though that the bulk of carbon is sequestered in long term store it makes sense that long term storage is much more stable. Short term cycling accounts for ten to one hundred times more volume of carbon movement annually then does long term. Of note though is human activity that moves carbon from long term storage to short term primarily through fossil fuel combustion and cement making. Humans are upsetting the balance of the cycle, consequences of which are yet to be fully substantiated but are believed to be causing climate change.

Short term cycling is referring to the fluxes that occur annually within the atmosphere, terrestrial ecosystems and the ocean surface. This is considered short term because massive amounts of carbon may move into and out of these three reservoirs within minutes, hours, days or years. Conversely, the bulk of carbon that enters into a long term reservoir, the deep ocean and the Earth's crust, it will be sequestered there for thousands to hundreds of millions of years.

Carbon Exchange: Short Term Cycling

Short term cycling involves the following movements of carbon: ocean surface to the atmosphere, atmosphere to the ocean surface, atmosphere to terrestrial ecosystems, and terrestrial ecosystems to the atmosphere.

Carbon Exchange: Short Term Cycling: Ocean Surface and the Atmosphere

Annually 92GT of carbon is moves into the ocean surface from the atmosphere and vice versa, from the ocean surface to the atmosphere just 90GT annually. The variance is due to human activity releasing carbon dioxide into the atmosphere and ultimately upsetting the balance. This is resulting in an immediate change to the volume of carbon found in the ocean surface which is having dire consequences for ocean life because this increased dissolved carbon dioxide is ultimately driving the pH of the ocean down. This phenomenon is called ocean acidification and will be discussed following a brief description of the processes involved in carbon movement between these two short term stores.

The dissolving of carbon dioxide into the ocean and the release of carbon dioxide from the ocean is controlled by the pressure of carbon dioxide in the two reservoirs. The carbon dioxide pressure is constantly equalizing between the two stores through the passage of carbon dioxide between them. One can account for this flow of carbon knowing that cold water can dissolve more carbon dioxide than warm water.

Gaseous carbon dioxide dissolves readily into the ocean. As carbon dioxide (CO_2) dissolves into ocean water it forms carbonic acid (H_2CO_3). This carbonic acid then breaks down to form hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). Bicarbonates break down to H^+ and carbonate ions (CO_3^{-2}). Carbonate ions are used by shell forming organisms through binding with calcium ions to form calcium carbonate ($CaCO_3$). Many of the shell forming organisms are microscopic and as they are consumed their shells are likely metabolized and the carbon is incorporated into the consumer. Subsequent consumption by larger and larger animals will ultimately result in this carbon being released through respiration, excreted and dissolved, or excreted and deposited on the ocean floor. Ultimately, the carbon may be involved in numerous chemical and biochemical reactions throughout the year. Following the release of carbon dioxide via respiration it may easily diffuse out of the water and back into the atmosphere as a gas.

Secondly, carbon dioxide is used in photosynthesis by phytoplankton, marine algae, and marine plant life. Photosynthesis in the marine environment is identical to that which occurs on land. Driven by the light energy, or photons, the chloroplasts within the cells of photosynthesizing organisms form carbohydrates. The reaction is as follows:

Carbon Dioxide (CO_2) + Water (H_2O) + Light Energy -> Carbohydrate ($C_6H_{12}O_6$) + Oxygen (O_2)

These carbohydrates are used in respiration either by the organism that created them, the producer, or by a consumer. Most all organisms process carbohydrates for their chemical energy in a process called cellular respiration. These carbon based molecules go through the following generalized reaction:

Carbohydrate ($C_6H_{12}O_6$) + Oxygen (O_2) -> Carbon Dioxide (CO_2) + Water (H_2O) + Chemical Energy

One can imagine that the released carbon dioxide may now dissolve and form carbonic acid, be used by a producer, or perhaps diffuse out of the ocean and into the atmosphere. Between these two reservoirs carbon is moving back and forth throughout the year resulting in the flow of 90GT of carbon moving both into and out of the ocean surface. Of note is that about 2GT is transferred from the ocean surface to the deep ocean with the shell remains of organisms as the vehicle.

There is currently concern about this balance being upset both directly by the release of carbon dioxide by human activity and indirectly by possibility of anthropogenic carbon dioxide causing climate change. Both of which are leading to an acidification of the ocean wherein the normal chemical reactions involved in the cycle are disrupted by the increase of free hydrogen ions.

Ocean acidification caused by an overabundance of carbon dioxide being dissolved, leading to an excess of carbonic acid, unfortunately leading to the formation of bicarbonate ions. Though it is normal for there to bicarbonate ions as carbonic acid breaks down to carbonate, the excess free hydrogens cause the reaction to shift and favor the formation of bicarbonate. Bicarbonate is not a useable ion for shell forming organisms, they require carbonate ions to make calcium carbonate. This is affecting the entire food web of the ocean and may ultimately have dire consequences.

Climate change, whether anthropogenic or not, is causing the upwelling of carbon rich water from depths beyond the ocean surface. Recall that cooler water can dissolve more carbon dioxide. This upwelling is bringing bicarbonate to the ocean surface and acidifying the waters. The upwelling may be caused by increased wind activity along the coastline, pushing surface water out to sea to be replaced with deep ocean water rich in carbon.

Carbon Exchange: Short Term Cycling: Atmosphere and Terrestrial Ecosystems

Terrestrial ecosystems contain about 2100GT of carbon at any given time. The modern atmosphere contains some 750GT of carbon. Annually 120GT of carbon is being exchanged between and within these two reservoirs through natural activity. An additional 9GT is being released into the atmosphere through human activity. Through respiration and decay 120GT of carbon is released into the atmosphere annually. Conversely through photosynthesis 60GT of carbon is sequestered from the atmosphere annually by terrestrial plants and 60GT moves from plants to soils via consumption and metabolism or death and decay. Though the terrestrial ecosystems and the atmosphere pale in comparison of volume of stored carbon when compared to the Earth's crust of that of the ocean, the activity of carbon flow between them is of great importance.

Photosynthesis, as discussed earlier, is the biological process by which light energy is used by photosynthetic organisms to convert gaseous inorganic carbon dioxide into organic carbohydrate molecules. Annually this accounts for 60GT of carbon being pulled from the atmosphere to make carbohydrates. This is 6×10^{13} kilograms of carbon a year. In more understandable terms, if one kilogram is equal to 2.20462 pounds, that is roughly 1.24×10^{14} pounds of carbon annually. Therefore on a daily basis 3.4×10^{11} pounds of carbon is being biologically processed by photosynthesis. Consider that the planet's terrestrial surface is only 29% of the total and furthermore this is not accounting for Antarctic and other snow covered regions as well as deserts.

The terrestrial producers, when considering a food web, produce the food for the consumers. As plants are consumed the carbon rich molecules are metabolized and carbon becomes incorporated into molecules of the producer, liberated as carbon dioxide through respiration, or excreted. Additionally, the producer itself may utilize sugars produced through photosynthesis in cellular respiration, releasing the carbon back to the atmosphere. In any case, carbon is moving through and into and out of the terrestrial ecosystem relatively quickly. At this point it may be useful to reflect on the law of conservation of mass as you imagine a single carbon atom on a journey through the different reservoirs and processes that move it along.

If a plant is not consumed while living, its remains will ultimately fall to the ground and become incorporated into the soil. Soils are teaming with microorganisms that will break down organic materials and the carbon will be moved along through various biological processes until it is ultimately released as carbon dioxide gas. Annually 60GT of carbon moves from the living plants and animals of the Earth's surface to the soil by means of excretion, death, and decay.

Annually a combined total of 120GT of carbon is released, primarily in carbon dioxide, by land plants, animals, and microorganisms of the soil.

Carbon Exchange: Long Term Cycling

The slower aspects of the carbon cycle, deemed long term cycles, are the formation of rocks and fossil fuels. Both of these processes can take thousands to millions, even hundreds of millions of years. By all accounts, 99.958% of the carbon on this planet is "locked" up in the crust. The majority of which is bound in rock formations with just a tiny, albeit important, fraction amassing to 4000GT of hydrocarbons. Hydrocarbons, such as coal and oil, drive this world's economy, food production, and transportation. Human activity is intimately associated with the carbon cycle and we have an impact on what is likely the slowest of the cycle processes. Fossil fuels that can take hundreds of millions of years to form are being cycled out of storage and into the atmosphere in minuscule geologic time lengths of hundreds of years. Though this may be a point of discussion later on in this unit, it is always useful to set a perspective along the way.

Rock formation, as discussed previously, occurs because of accumulation of organic matter over time that is then covered with successive layers. As the layers pile up the pressure produced on lower levels is sufficient to compact the material into rock. Heat and other tectonic forces play a role as well. Recall that limestone is primarily the shell remains of aquatic organisms and that shale is organic remains mixed with mud and silt. At some point the carbon that is sequestered in rock was once free in the atmosphere, free to be cycle between ocean, air, and terrestrial ecosystems relatively quickly. Year after year just a fraction of carbon is steered towards a long term cycle, rock formation, wherein it will be bound for millions of years. On average over time, an approximately equal amount is liberated from rock annually to again be an active player in short term cycling. Upheaval of rock layers through tectonic activity, exposure of rock from tectonic events, and volcanoes are all methods that set in the motion the movement of carbon out of the store we call the Earth's crust. Once exposed to the atmosphere rocks are weathered by acid rain and carbon contained within is gassed off as carbon dioxide or transported to soils, rivers, lakes, and oceans as dissolved carbonates.

The carbon that is stored in hydrocarbons and considered as part of the world's carbon store amounts to about 4000GT. This is the estimate for all the carbon within all the Earth's coal, oil, and natural gas. The formation of fossil fuels differs from the formation rock in that fossil fuels are derived almost wholly from organic matter. Though it is often assumed that the fossil fuels that we so enjoy today are composed of the carbon that was once the dinosaurs of yesterday, this assumption is wrong. The majority of fossil fuels available were formed from the remains of flora and fauna from times before the dinosaurs. This idea helps one conceptualize just how old this stored energy is. This essentially ancient sunlight is the product of photosynthesis that occurred upwards of three hundred million years ago.

Fossil fuel formation is similar to sedimentary, carbon rich, rock formation in that the carbon was previously within living organisms. Where fossil fuels differ is that they are formed primarily of organic matter, large pockets and layers of organic matter subjected to the same heat and pressure that forms rocks but so rich in organic content and lack in rock that the outcome is a hydrocarbon, the similarities are only general though. Fossil fuels come from a time of a warmer Earth, tropical plant life flourished throughout the globe on land masses distributed differently than today. Ancient swamps, rich in vegetation are the source. Layers of fauna, from microscopic phytoplankton and protoplankton to massive ferns, deposited on swamp bottoms over generations and slowly decayed. The slow rate of decay is attributed to the swampy environment being saturated with water and creating an anoxic zone for the organic matter to rot. This slows the rotting process and layer upon layer of matter accumulated. Periodic changes in sea level would wash up sediment depositing a layer of sand and silt on top of the thick layer of organics. This resulted in massive pockets of material rich in carbon. Over time this process occurred again and again pushing older layers deeper and deeper as successive layers accumulated. This satisfied the necessary condition of pressure to compact the matter. As this layer is moved deeper into the Earth's crust it is also subjected to heat. The four conditions needed to produce fossil fuels, large stores of carbon rich organic matter, an aerobic environment, intense pressure, and heat were satisfied repeatedly over time some three hundred millions years ago. If it was not for this period of time when the planet was covered in massive swamps we would likely not be enjoying the benefits of hydrocarbons today.

Human Impact on the Carbon Cycle

The carbon cycle can appear as daunting, but ultimately it can be compartmentalized and efficiently delivered through classroom instruction quite easily. If one uses the approach of first addressing where the carbon is and then discusses how carbon moves from store to store it is readily understood by students. Students can pull from their prior knowledge of the water cycle, content that is learned in middle school, and apply their understanding of cycles and conservation of matter to the carbon cycle. The important facet of teaching about the carbon cycle is working with students to help them understand that the cycle has been going on for millennia but that humans have been impacting the cycle in a substantial way for the last 50 years. With the background knowledge covered about where the carbon is and what natural processes are cycling carbon students can then begin to work with anthropogenic processes that move carbon. The important learning objective resides in students making connections between natural cycle processes and possible implications of human manipulation of the cycle through activities that upset the balance of carbon flow.

Human activity affects the carbon cycle in a few key areas, all of which fall within the realm of carbon release into the atmosphere. We release carbon by burning forests, burning fossil fuels, and production of cement. It is important to note that burning of forests is considered carbon neutral because the carbon sequestered in plants is considered short term storage. Moving carbon from terrestrial ecosystems through burning and from the Earth's crust by burning fossil fuels are likely prior knowledge for students, but cement making is not something that will have been covered in school previously. Secondly, we have to address the consequences of these activities and how they are compounding the problem of carbon release with acid rain production possible climate change.

Whether it is combustion of wood, oil, coal, or natural gas, carbon is liberated to release energy and carbon dioxide is formed. A combustion reaction, appropriate for a freshmen science class, is as follows:

Carbon Fuel Source (Oil) + Oxygen (O_2) + Fire -> Water (H_2O) + Carbon Dioxide (CO_2) + Heat Energy

Carbon Fuel Source (Natural Gas: CH_4) + Oxygen (O_2) + Fire -> Water (H_2O) + Carbon Dioxide (CO_2) + Heat Energy

The carbon fuel source may be a fossil fuel or wood, but the end result is the same in complete combustion, carbon dioxide production. Take note though that combustion of natural gas, methane, produces half the carbon dioxide of coal or oil combustion per unit of energy yielded. The carbon dioxide is a gas and once in the atmosphere it will take part in the natural carbon cycle again. The question is whether or not natural processes can accommodate the excess of carbon dioxide in the air. It seems that the answer to that question is “no”. Atmospheric carbon dioxide has been rising year after year. Readings of carbon dioxide taken since the 1960’s show that carbon dioxide levels have risen from 320ppm to almost 400ppm. There is evidence in the oldest Antarctic ice cores that carbon dioxide levels have not been this high in 800,000 years. We do not currently have a completely accurate way of predicting what the implications will be. Students need not be overwhelmed with theories about what may happen but should rather develop an understanding about how the natural cycle is being disturbed. Human activity moves carbon from stores to the atmosphere faster than the cycle can move that carbon back into stores.

Global cement production is the other key human activity that releases carbon dioxide. Limestone and other calcium carbonate rich rocks are used to produce cement through a process that makes lime (CaO). Though a significant amount of carbon dioxide is released in the energy intensive process of cement making by burning fossil fuels, the formation of lime also releases carbon dioxide.

According the Carbon Dioxide Information Analysis Center of Oak Ridge National Laboratory in Tennessee, human caused release of carbon for 2011 was 9.449GT. The release of carbon is accounted for as follows: 1.7GT from burning of gas hydrocarbons; 3.317GT from burning of liquid hydrocarbons; 3.997GT from burning of solid hydrocarbons; 0.491GT from cement production; and 0.063GT from gas flaring. Gas flaring is essentially the burning of combustible gases, by petroleum production plants or other industrial plants, that are deemed unusable by-products or waste products.

Classroom Activities

This section is intentionally brief as the focus of these units is to present content. Below I have included a few activities that are simple to do in class and have been received well by students.

Classroom Activities: Carbon Cycle Map

Set up the room in stations for the reservoirs and number them 1 through 12. You will need to break down reservoirs more than this unit has done. For example, categories such as “land animals” and “land plants” are used. You want to have 12 stations so that students can easily use a pair of dice to determine their movements. Assign pairs or small groups of students to start at different reservoirs. Record the starting reservoir and roll the dice. Move to the corresponding reservoir and record. The students then must determine what processes had to take place for carbon to move from the first reservoir to the next. Have them repeat this ten to twelve times in the period with their ending reservoir being pre-determined as it should be the same as the starting reservoir. Have students make a poster or other visual representation of their pathway and present it to the class. This will take two or three class periods.

Classroom Activities: Converting Watts to Carbon

Through the use of a simple calculation it is interesting to determine how much carbon is produced through the use of everyday electronics. Using an accepted conversion of 2.3lbs of CO_2 per kilowatt hour and then adjusting for just the carbon by dividing by 3.667. This conversion standard is based on the use of coal.

This is easiest if students pick items that operate for lengths of time. For example, a microwave has high energy consumption but in general it is only run for a few minutes a day. This makes the microwave a poor choice for this activity. Conversely, a computer or TV will be operating for hours and the numbers will be more concrete.

Find the wattage of the item of interest and multiply by the number of hours of operation. Divide this answer by 1000 to convert to kwh. Multiply by 2.3lbs/kwh to determine the mass of CO_2 emission. Divide by 3.667 to determine the mass of carbon.

Classroom Activities: Density of Carbon Dioxide

This activity helps to illustrate how dense carbon dioxide is which in turn helps students to make a connection to its greenhouse gas nature. Thought the reason that carbon dioxide is a greenhouse gas is quite complex and beyond the scope of the ninth grade, the students will remember that carbon dioxide is heavy and dense. You can create some carbon dioxide gas and pour it over a candle, extinguishing the flame.

You need a tea candle, lighter, beaker, baking soda, and vinegar. Light the candle. Add 15ml of vinegar to one teaspoon of baking soda in a 250ml beaker. Allow the fizz to rise and fall. Gently lift the beaker and with slow pouring action you can pour the carbon dioxide onto the flame. The flame will go out because of the lack of oxygen as it is covered in carbon dioxide gas. Do not pour liquid onto the flame, only the gas. You cannot see it. Do a trial run before doing this with the class.

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Implementing State Standards

Connecticut Grade 9 Content Standards

9.3 - Various sources of energy are used by humans and all have advantages and disadvantages.

9.4 - Atoms react with one another to form new molecules.

9.5 – Due to its unique chemical structure, carbon forms many organic and inorganic compounds.

9.7 - Elements on Earth move among reservoirs in the solid earth, oceans, atmosphere and organisms as part of biogeochemical cycles.

9.8 - The use of resources by human populations may affect the quality of the environment.

9.9 - Some materials can be recycled, but others accumulate in the environment and may affect the balance of the Earth systems.