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Petroleum: Our Best Transportation Option?

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Introduction

Our current primary source of energy, fossil fuels (coal, oil, and natural gas) has many costs associated with it. These costs are not just those involved with the extraction, processing and transportation of the fuels. Societal costs of fossil fuels include human health problems due to air pollution and environmental degradation caused by acid rain, global warming, and water pollution. The continued use of these fuels since the dawn of the Industrial Revolution to power all aspects of society has released the amount of carbon that was sequestered for millions of years into the current atmosphere in a very short time. With this large input, we have upset the global balance of carbon to the point that we have the highest concentration of carbon dioxide (CO_2) for the last 650,000 years [1]**.** This substance is increasing at an exponential rate and within the current generation's lifetime, the CO_2 concentration will most likely double pre industrial levels. In order to understand the global balance of the carbon cycle, this unit will include hands-on field measurements, remote sensing, and estimation of where carbon is stored and how it is exchanged between the Earth's surface and the atmosphere. Looking through the research and technical articles through the curriculum unit writing process, I conclude that our options to lessen the effects of the increased levels of CO_2 are to manage terrestrial lands to sequester more carbon and reduce the amount of CO_2 produced through our daily lives. With this in mind, I am going to lead my students through investigations to determine the carbon sequestering capacity of our local environment, make the case for conserving our petroleum resource for feed stock for products instead of burning it all as a fuel, and have students research alternatives to current transportation fuels to determine the best options for transportation in order to lower the carbon output of our transportation sector.

The intended audience for this curriculum unit is 10 th grade vocational students enrolled in my Environmental Landscape Technology Program. These students will spend the first four and a half weeks of their sophomore course engaged in this unit to learn a number of skills from their task list. Topics included in this unit include gathering data in the field, analyzing data and maps, and synthesizing their data into written reports. Students will engage in a number of land-cover and soils-related protocols including biometry measurements of woodlands and characterization of woodland soils. This unit will also explore the carbon cycle almost in a "cradle to grave" sense, starting with plants fixing carbon using solar radiation during the process of photosynthesis, tracking inputs from anthropogenic sources (most notably transportation), exploring the global fluxes of carbon and cycling into the carbon sinks and quantifying how carbon is sequestered by our oceans and our terrestrial systems. Many science and mathematics concepts seem to make no sense to students since they cannot see the relevance to their application. Through the context of environmental science, students can see relevance to biological and physiological processes, chemical reactions and mathematical calculations and interpretation. Students must understand that environmental science is not a secondary and useless science: it is the real application of many aspects of science, math and English and is very multidisciplinary in nature. This unit would lend itself well to any environmental science class. I hope that you will be able to implement some of this unit into your environmental science class to improve the engagement of your students and to also put some real science into your classes. I think of my classroom as a catalyst for intrinsically motivating students about the environment. I strive to do this by developing relevant and engaging curriculum units which is ultimately how to increase the students' understanding of content and empower students with the ability to analyze information and develop their higher order thinking skills.

Being a vocational instructor, I see first hand the importance of active discovery of skills and content information, compared to passive reception of information in a lecture context. This rings true and can be performed in a classroom setting. This is further enhanced with hands-on vocational skills that are part of this unit. The hands-on activities that are incorporated into this unit mimic the actual tasks that a research scientist or environmental field technician would do as part of their job. This puts the students in practical learning situations that are relevant and most times bring about an intrinsic motivation for learning the content. The data collected by my students will be uploaded to the NASA G.L.O.B.E. website (www.globe.gov) via the Internet, which also helps with the motivation, since they are engaging in an international data-sharing project. Students can appreciate the data they will be analyzing much better if they have actually collected some data in the field themselves. Having students analyze data throughout the unit helps develop creative and critical thinking skills that are usually not developed in normal classroom instruction.

Many of the ills in the environment today are tied to the use of fossil fuels for the production of the products our society uses, energy production, and transportation. Talking to students about polluting power plants and factories does not really connect them to their role in burning fossil fuels and contributing to pollution. Start talking about cars with teenage students and you gain the attention of the whole class. Most of the students do not see cars as a polluting technology. They see cars as a necessity to get to and from school and their jobs.

When speaking with students about cars their biggest complaint is about how much it costs to buy gas for their car. If asked where the gasoline comes from they will tell you that it is taken out of the ground and put into the tank trucks and then taken to the local gas stations. They do not know the whole story about all the processing and effort it takes to make that gallon of gas they burn up so readily in their own personal internal combustion engine. Teaching students about the origins and the processing of crude oil into products really gives them a better appreciation for this amazing non-renewable resource. My goal is to have the students realize that this resource is so unique and that we need to conserve it for making the myriad of products derived from it instead of turning 90% of each barrel into fuels that are burned and emit heat and pollutants to the atmosphere.

The first day of the unit, students are placed into groups that will research and present to the class how different alternative/renewable energies could be used to power our transportation. The student groups will be given a binder that includes journal articles, Internet resources, and other information on the specific alternative fuel. Student groups will read through and decipher the information in the binder as well as "researching the research" on the web to develop a multimedia presentation. The sheet I will use to assign the project to my students is included at the end of the unit under lessons. The students will be given a rubric indicating the minimum requirements for the presentation but have quite a bit of creative license when developing their presentation. This project will be done outside of the class and will be the responsibility of the research group. We are fortunate that the students are able to stay after school for extra help on Tuesdays and Thursdays throughout the year and are provided with transportation home. This also helps build a group dynamic and an overall good work ethic since students are required to interact and take responsibility for learning outside the classroom.

Crude Oil

Crude oil formed by the action of heat and pressure on the remains of microscopic plants in the ocean over millions of years. These plants absorbed energy from the sun and stored it as carbon compounds in their bodies. When they died their bodies sank to the bottom of the oceans and the remains were buried by sediments which caused anaerobic conditions which did not allow them to decay. As sedimentation continued these remains were put under more and more pressure and heat that eventually turned them into crude oil. The sedimentary rocks crude oil formed under are usually porous and allow fluids and gases to pass through. Since oil is less dense than water, the crude oil passed through the rock and rose up until it naturally seeped onto the land or into the ocean, or it was stopped by a layer of impermeable rock which trapped the crude oil underground.

This crude is a mixture of a number of substances made up of predominately hydrocarbons. Hydrocarbons are compounds which contain primarily hydrogen and carbon atoms. The different hydrocarbons have different boiling points. This range of boiling points allows the separation of the mixture by fractional distillation with a fractionating column. Within this structure, crude oil is heated with high pressure steam to 600 $^{\circ}$C and hydrocarbon gases are released. The smaller the hydrocarbon molecule, the further the gas rises up the column before condensing back into a liquid. The larger the molecule is (the more carbons it contains), the higher the condensing temperature will be, the more viscous the fluid will be, and the less volatile and less flammable it is.

To illustrate why crude is so important to our society, you should discuss the different fractions that are separated in the column. The petroleum gas fraction is made up of small compounds with four or less carbons with a boiling point up to 60 $^{\circ}$C and is used for heating, cooking, and making plastics. The naphtha fraction is made up of compounds that have between five to nine carbons with a boiling point of 60-100 $^{\circ}$C and is the fraction that is further processed to make gasoline. The kerosene fraction is made up of compounds with 10 to 18 carbons and aromatics with a boiling point of 175-325 $^{\circ}$C and is used for fuel for jet engines and tractors and as starting materials for a number of products. The gas oil fraction is made of compounds containing 12 or more carbon atoms with a boiling point of 250-350 $^{\circ}$C and is used for diesel fuel and heating oil and as starting materials for a number of products. The lubricating oil fraction contains long chain compounds with 20 to 50 carbon atoms with a boiling point of 300-370 $^{\circ}$C and is used for motor oil, grease, and other lubricants. The heavy gas fraction is made of long chain compounds with 20 to 70 carbon atoms with a boiling point of 370-600 $^{\circ}$C and is used for industrial fuel and as starting materials for a number of products. The residuals from the fractioning column are multiple-ringed compounds with 70 or more carbon atoms with a boiling point of greater than 600 $^{\circ}$C and are used for asphalt, tar, waxes, and as starting materials for a number of products [2].

Approximately 90% of the crude oil is converted into some type of fuel. Of the remaining 10%, about 5% is used to produce plastics. The other 5% is used to make dyes, inks, household detergents, pharmaceuticals, and a wide range of compounds suitable for a variety of applications [3]. The distillation process is illustrated in the lesson Distillation of Simulated Crude Oil at the end of this unit. The materials to run this lab can be bought as part of the science and sustainability kit from the science education for public understanding program (SEPUP).

The field of chemistry that studies these hydrocarbons is called organic chemistry. You may think this is an interesting name since anytime when you hear the term "organic" now, you automatically think of the most pure food or substance. These substances derived from hydrocarbons are called organic since early chemists thought that plants and animals were needed to produce them. However, chemists now know how to make organic compounds without any assistance. Chemists can take advantage of the properties of these compounds to derive all sorts of products used in our society. This is made possible by the building block of life, carbon.

Carbon is such a special case in chemistry as a result of the combination of its properties, including the number of valence electrons on a neutral atom, its electronegativity, and its atomic radius. Carbon has four valence electrons, and it must either gain four electrons or lose four electrons. The electronegativity of carbon is too small for carbon to gain electrons from most elements to form C^{4-} ions, and too large for it to lose electrons to for C^{4+} ions. Carbon forms covalent bonds with a number of other elements, including big players like hydrogen (H), nitrogen (N), oxygen (O), phosphorous (P), and sulfur (S) found in the environment. Because carbon atoms are relatively small, they can come close enough together to form strong C=C double bonds or even triple bonds. Carbon can form strong multiple bonds to nonmetals such as N, O, P, and S. No other element can provide the variety of combinations for life to exist.

Hydrocarbons are named according to the number of carbon and hydrogen atoms they contain. Compounds that contain as many hydrogen atoms as possible are said to be saturated. This group of saturated hydrocarbons is known as the alkanes. The simplest of these is methane (CH_4) this molecule combines the four valance electrons in a neutral carbon atom with four hydrogen atoms. Looking at methane, you can explain to students the general rule that carbon is tetravalent, in other words, it forms a total of four bonds in almost all of its compounds. This structure minimizes the repulsion of the pairs of electrons in the four C—H bonds. If your classroom is equipped with ball and stick molecular models kits, having students build this will illustrate the tetrahedral geometry of the carbon atom.

Have students predict what longer carbon chains would look like and what their chemical formulas would be, using the fact that carbon is tetravalent. Compounds that contain more than one carbon usually are held together by single or double C—C bonds and since they are tetravalent, the formula of the compounds have a pattern. The generic formula of the compounds can be better understood by the students by pointing out that the compounds contain chains of CH_2 groups with an additional hydrogen atom capping either end of the chain. You can have students plug and chug using the following: for every n carbon atoms there must be 2n+2 hydrogen atoms C_nH_{2n+2}.

Students have no idea about the myriad of products in our lives that are made from petrochemicals. There are many products used everyday yet they do not fully understand their origin. Using the very complete list of products found on the web [4], have students determine the raw material from crude oil that was used to produce the particular product. Students should research that material and determine the structure of the hydrocarbon compound that it is derived from. Have students research the properties of the material and the other applications and uses for this compound in our society. Students should also research the behavior of the compound once it is released into the environment and any potential ills associated with it. Finally, students should postulate what would happen if we did not have this material to use to make products and what that would mean for our society.

Gasoline in Automobiles

When you think of petroleum products the first thing that comes to mind for most of us is gasoline. Gasoline is in the fraction that has a boiling point between 40-100 ^{o} C. It may contain over a thousand compounds within the fraction. The property we are all familiar with is the octane number. What this number equates to is the tendency of an engine to knock or make noise as it combusts in the engine, no knocks mean that the fuel is combusting in a controlled manner. The number tells you the percentage of isooctane (C_8H_{18}) to heptane (C_7H_{16}). Therefore gasoline with an 87 octane rating would have 87% isooctane and 13% heptane [5].

Combustion of gasoline is a reaction and it gives off products. Perfect combustion of a hydrocarbon with oxygen in the air would convert all the hydrogen in the fuel to water and all the carbon in the fuel to carbon dioxide. Nitrogen in the air would remain unaffected. The combustion process in a typical engine is not "perfect". Due to this nature of engines, side reactions happen with compounds other than oxygen and impurities in gasoline and there are several pollutants emitted.

In order to illustrate this to the students, have them build molecular models of methane, ethanol, and octane molecules and then "combust" them with oxygen. Doing these manipulations will help students determine the balanced chemical equations for these combustion reactions. This will also show how much CO_2 is produced when these fuels are burned. Using standard bond energies, you can than calculate and compare the amount of energy released during these combustion reactions.

Car exhaust is not a simple thing to analyze. Current fuels for vehicles are derived from crude oil which is produced primarily from the decay of marine organisms. This crude contains many elements. The most common elements being carbon, hydrogen, nitrogen, oxygen, and some sulfur. When the hydrocarbons and organic compounds containing nitrogen and sulfur are burned, the products are water, carbon dioxide and monoxide, oxides of nitrogen and oxides of sulfur. Many of the hydrocarbons pass through the internal combustion engine unconsumed and are released along with other exhaust fumes in the tailpipe. Energy efficiency of city driving falls below 15%, and the majority (approximately 80%) of cars are driven in cities. This equates to having only 1.5 gallons of usable fuel in a 10 gallon tank and the remaining 8.5 gallons are transformed into heat and pollutants [6].

Having students use Drager tubes to collect samples of exhaust will be a good way to start out an analysis of the pollutants. These tubes are placed into a piece of vinyl tubing and connected to a large syringe. The tube is place in the stream of exhaust of a vehicle and then the sample is taken. The tubes applicable to this are the carbon monoxide, carbon dioxide, and hydrocarbon gas-detector tubes. These tubes can be purchased through a scientific supply company. Having students collect samples from various types of vehicles: cars, vans, SUVs, trucks, as well of different types of fuels: gasoline, diesel, biodiesel blends, will make for an interesting data set.

Ideally you can ask the state to bring some emissions-testing equipment to your school and test vehicles that your students or teachers drive to school each day. This will make for more accurate data and most likely more parameters you can analyze. I was fortunate to acquire the data for this testing for a number of vehicles at a colleague's school that I can use with my students. This type of data manipulation makes these numbers seem more relevant to your students.

Pollutants from Car Exhaust

Carbon dioxide (CO_2) is a naturally present gas in the atmosphere. The burning of fossil fuels in an internal combustion engine is a significant contribution to the increasing concentrations of this principal greenhouse gas. Currently, according to NOAA and the Scripps Institution, the Earth's atmosphere has 384 ppm (parts per million) of CO_2, a rise of almost 10 ppm in four years from 375 ppm in 2002, and a rise of almost 70 ppm in the last fifty years from 315 ppm in 1958 when the recording started at the Mauna Loa Observatory in Hawaii [7].

Carbon monoxide (CO) is produced by incomplete combustion when carbon in the fuel is partially oxidized rather than fully oxidized into carbon dioxide. The Earth's atmosphere contains only 0.1 ppm of carbon monoxide. This concentration can be much higher in an urban setting with the large number of vehicles. Concentrations can reach 50 or even 100 ppm, which is well over safe levels [8]. Catalytic converters were installed in cars after 1975 with the primary function being to convert CO to CO_2 in the presence of air and a metal catalyst. This has been a great environmental achievement. Since this time, the number of cars has doubled, and the amount of CO in the air has decreased by 40% [8].

Volatile organic compounds (VOCs) are emitted when fuel molecules in the engine do not burn or are only partially combusted. VOCs are organic compounds that contain hydrogen and carbon atoms. They are a major contributor to ground level ozone. Newer technologies in catalytic converters include a catalyst to oxidize these partially burnt hydrocarbons completely to CO_2. Changes to fuel caps, vapor recovery devices on fuel pumps, and improvements of fuel lines have reduced the evaporative emissions of hydrocarbons associated with automobiles. Polar VOC molecules called aldehydes cling together in the atmosphere to form tiny liquid particles called aerosols. These aerosols in conjunction with soot are responsible for the haze of smog [8].

Nitrogen oxides (NOx) are primarily produced when elemental nitrogen in the air is broken down and oxidized inside the internal combustion engine. Nitrogen oxides play a role in the formation of ground level ozone and acid rain. Atmospheric oxidation of NO leads to different oxides of nitrogen and eventually to nitric acid, a significant source of acid rain. The sunlight catalyzed reaction in the atmosphere between unburnt hydrocarbon molecules and NOx leads to photochemical smog. A product of this reaction is ozone. Catalytic converters do include a catalyst for reducing NO back to N_2 and O_2; this does have some problems, though, in the presence of the oxidation catalyst used to remove CO. Even though the number of automobiles has doubled, the NOx levels have remained almost constant. This is also attributed to the improved engine design and improved gasoline formulations [8].

To better understand the magnitude of the amount of these pollutants that are being produced in the local community, have students complete the Determining the Amount of Emissions Emitted by Local Commuter

Vehicles activity at the end of this unit. The data used to make this activity are the actual data from my county and reflect the actual values of pollutants mentioned above in this section emitted by motor vehicles. You can get the data for your city or county from the city data website [9]. These calculations will be revisited later in the unit when we look at the amount of carbon that can be sequestered by our terrestrial carbon sinks through management of forest resources.

Pollution Effects from Transportation

Tropospheric Ozone

One can see the most immediate effects of emissions as ground-level ozone, associated with the brown haze around many of our cities. Ozone is formed when volatile organics are passed through exhaust to the atmosphere where they react with nitrogen oxides. These reactions are stimulated by sunlight, particularly ultraviolet light, and the rate of reaction is relative to both temperature and intensity of sunlight. These conditions are why we see many ozone action days in the summer in Delaware. According to the Ohio EPA, emissions from car exhaust account for about 60% of ground level ozone in cities.

As discussed before, the internal combustion engine does not fully consume the hydrocarbons in gasoline and also oxidizes some nitrogen. This means there is a high concentration of NOx given off by our vehicles. The excess amount of NO_2 drives the formation of ozone and NO destroys ozone. When the ratio of NO_2 to NO is over three, ozone concentrations rise readily.

Global Warming

You or your students may ask what causes the greenhouse effect. Under normal conditions, the atmosphere naturally traps only a portion of the outgoing infrared radiation. With the increase of greenhouse gases in our atmosphere, the proportion of the infrared radiation that is being trapped is increasing. Looking at this trend with a basic understanding of laws of balance and conservation, you should realize that inputs should equal outputs in order to keep equilibrium. If we are seeing less and less output of infrared radiation from our atmosphere, heat will pile up and cause warming. Of the greenhouse gases, CO_2 is the most notable since it constitutes about 80% of the greenhouse gas emissions. We emit CO_2 when we burn fossil fuels to power our communities, transport ourselves, produce the products we use in our lives, or when we burn our forests.

Our cars and light trucks contribute 20% of the total CO_2 emissions. The U.S. has the lowest standards for gas mileages in the world, with Japan's average nearly double the average American vehicle. For example, using the EPA's 2000 fuel Economy Guide, a 2000 Dodge Durango (produced here in Delaware!) gets twelve miles per gallon in the city and will produce approximately 800 pounds of CO_2 in a distance of 500 city miles. A 2000 Honda Insight that gets 61 miles to the gallon will only produce approximately 161 pounds of CO_2 over the same 500 city miles. Imagine how much we could reduce the carbon emissions from our cars if the gas mileage standard was increased. We have the technology to do it; we just need more U.S. consumers to buy vehicles based on fuel economy. Other forms of transportation also play a significant role in carbon emissions. Another 13% of the U.S. carbon emissions come from large, mostly commercial, trucks. The IPCC estimates that aviation also contributes 3.5% of the emissions and this could increase to 15% by 2050 [10].

There are numerous things to understand and discuss with your students about with the issue of global warming. In this unit, I wanted to mention global warming and to talk briefly about how transportation is contributing to this problem. If you are interested in teaching more about global warming please check out my unit from the 2006 National Seminar on The Science of Global Warming. This unit is a very in-depth look at global warming and the possible effects it may have on the environment. This unit also includes quite a bit of background information you can use to better understand the science behind this issue.

At this point, the students have been enlightened to the potential petroleum has for feed stocks for an enormous amount of products we use everyday in our society. Students have also explored and quantified the large amount of pollutants that are emitted into our environment by burning petroleum in our vehicles and the very real and very immediate problems we are facing due to using it in this way. Lead a discussion on the pros and cons of using petroleum as our sole transportation fuel. This discussion will model for the students the types of information you would like them to include in their unit project on transportation fuels, since that is one component that must be included in their project. Students should realize that it is more beneficial to use petroleum to create products than to burn it.

Carbon Cycle

Carbon accounts for approximately 50% of the dry mass (water removed) of plants and animals and is present in all aspects of the planet [11]. It is in the land, the atmosphere and the oceans. Over time it is cycled in and among all of these components. This carbon cycle has a large impact on Earth. Globally, the carbon cycle influences the Earth's climate by regulating the amount of CO_2 in the atmosphere. Land-based ecosystems store as much carbon as the atmosphere, so plants and soils play an important role in regulating climate. The carbon cycle is also a factor in keeping ecological systems in balance. The atmosphere itself contains nearly 800 billion gigatonnes of carbon (GtC), which is more carbon than all of the Earth's living vegetation contains [12].

Biological organisms play an important role in the carbon cycle through the processes of photosynthesis and respiration. Almost all forms of life depend upon the production of sugars from solar energy and CO_2 through photosynthesis and the metabolism of the sugars to produce energy through respiration.

Photosynthesis is a process by which green plants absorb solar energy to remove CO_2 from the atmosphere and combine the CO_2 with water in the presence of chlorophyll to produce carbohydrates (sugars) and oxygen O_2. This is a complex series of chemical reactions that happens within the plant cells. This process is the original source of all important fuels including oil, coal, wood, and natural gas. You can also look at this process as the source of all our foods. . .how is that for importance! For my purposes in this unit, I will give a bit of background on this and not focus on these reactions, but if you are interested in an excellent explanation and in-depth analysis of this please refer to Connie Wood's unit from the same 2007 National Seminar on Renewable Energy.

Photosynthesis is carried out in organelles in plant cells called chloroplasts. They contain a pigment called chlorophyll. Chlorophyll appears green since it absorbs the blue and red wavelengths of light and reflects the green wavelengths. This pigment is responsible for trapping the sunlight for the reaction to occur. In a simplified explanation of photosynthesis, CO_2 and water are the raw materials used to form glucose and oxygen. The balanced reaction can be written as: $6 CO_2 + 12 H_2O \longrightarrow C_6H_{12}O_6 + 6 H_2O + 6 O_2$. Looking at this reaction, you see that water is both a reactant and product. This is because there are two steps involved in photosynthesis; the light and dark reactions. In the light reactions, light energy is converted to chemical energy and water is split into hydrogen and oxygen atoms. In the dark reactions, carbohydrates are formed from the carbon dioxide and hydrogen atoms. They both occur in the chloroplasts, and please do not confuse the idea that dark reactions occur at night. These reactions both occur in the daylight; they are simply called dark reactions since they do not require light energy. Structurally, the chloroplast contains stacks of membranes called grana which store the chlorophyll; they are surrounded by what is called the stroma. The light reactions occur in the grana, while the dark reactions occur in the stroma.

Respiration can be seen as the opposite of photosynthesis. In respiration, plants start with glucose which is broken down in the presence of oxygen and releases both water and carbon dioxide along with all the energy that was stored in the bonds. The reaction for respiration can be written as: $C_6H_{12}O_6 + 6 H_2O + 6 O_2 \longrightarrow 6 CO_2 + 12 H_2O$. Respiration occurs in a structure called mitochondria. Respiration takes the biologically fixed carbon back to the atmosphere.

The amount of carbon taken up by photosynthesis and released back into the atmosphere by respiration each year is 1,000 times greater than that which moves through the geological cycle [12]. This major exchange of carbon through biological processes can be seen if you look at the oscillations in atmospheric carbon dioxide concentrations. Over the course of a year, the biological fluxes of carbon are ten times greater than the amount of carbon introduced to the atmosphere by fossil fuel burning, although currently we are seeing the effects of this input increase dramatically.

In magnitude of the global carbon cycle, human activities contribute a relatively small amount of carbon, primarily as CO_2. Fossil fuel combustion adds less than 5% to the total amount of carbon released from the oceans and land surface to the atmosphere each year. CO_2, alone, is responsible for over half of the change in Earth's radiation balance. CO_2 concentration in the atmosphere currently is approximately 380 ppm [13]. Carbon dioxide released from fossil fuel combustion mixes readily into the global carbon pool. This increased concentration in the atmosphere is increasing so rapidly, since we have released in a couple of hundred years what took millions of years to accumulate geologically. Where fossil fuels are burned makes relatively little difference to the concentration in the immediate atmosphere, emissions in any region of the Earth affect the concentration of CO_2 everywhere else in the atmosphere. Concentrations of CO_2 are slightly higher in the northern hemisphere compared to the southern hemisphere, by several ppm, because most of the emissions of CO_2 from human activities happen there.

The oceans, vegetation, and soils exchange carbon with the atmosphere constantly. Carbon from fossil fuels is not exchanged with the atmosphere but transferred one way from geologic storage. Some of the CO_2 currently in the atmosphere may become fossil fuels someday, after being captured by photosynthetic organisms, and buried and subjected to heat and pressure to form, but the process takes millions of years.

How much carbon can be stored in each pool, especially the atmosphere, is a key factor in determining how severe global warming will be. Oceans, soils and vegetation are considered sinks for carbon since each takes up carbon from the atmosphere. We must also realize that each is a source of carbon for the atmosphere, because of the constant exchange between them and the atmosphere. Whether these storage pools are net sinks or net sources of carbon in the future depends on the balance of mechanisms that drive their behavior and how they change.

Over 90 GtC of carbon is exchanged each year between the atmosphere and the oceans, and close to 60 GtC is exchanged between the lands surface and the atmosphere annually. Human activities, fossil fuel combustion and land-use changes (such as building roads for transportation), contribute just less than 9 GtC to the atmosphere each year [14]. If the human contribution of CO_2 is removed from the equation, the average net flux, amount of CO_2 released to the atmosphere verses the amount taken up by the oceans, soils, and vegetation, is close to zero. This is reflected by the relatively stable concentration of CO_2 in the atmosphere, between 260-280 ppm, for the past 10,000 years prior to 1750 [15].

Currently the atmospheric concentration of CO_2 is almost 100 ppm higher than it was before 1750 because human activities are adding carbon to the atmosphere faster than the oceans, vegetation, and soils can remove it. This is occurring since the uptake processes are much slower than our current burning of fossil fuels. For example, about 45% of the CO_2 released from fossil fuel combustion during the 1990s has remained in the atmosphere, while the remainder has been taken up by the oceans, vegetation, and soils. CO_2 is also nonreactive in the atmosphere and has a relatively long residence time, although eventually most of it will return to the ocean and land sinks. To give you an idea of the persistence in the atmosphere, consider the following. About 50% of a single release of CO_2 will be removed within 30 years, a further 30% will be removed in a few centuries, and the remaining 20% may persist in the atmosphere for thousands of years [15].

The oceans accumulate more carbon than they emit to the atmosphere each year, acting as a net sink of about 1.7 GtC per year [16]. The oceans also have a huge capacity to store carbon compared to the land surface. Ultimately, the oceans could store more than 90% of all the carbon released to the atmosphere by anthropogenic sources, but the process takes thousands of years. Concern right now is on how the CO_2 is accumulating in the oceans and what impact that will have on ocean chemistry and marine life [17].

Carbon dioxide enters the oceans by dissolving into seawater at the ocean surface, at a rate controlled by the difference in CO_2 concentration between the atmosphere and the sea surface. Just like everything in nature, things move from a high concentration to a low concentration. The problem comes when the relatively small volume of surface waters become concentrated with CO_2. Mixing between surface waters and the deeper portions of the ocean is very slow, with some mixing taking hundreds of years [14].

As CO_2 is added to the surface of the oceans from the atmosphere, it increases the acidity of the sea surface waters, and impacts organisms. Corals and calcifying phytoplankton and zooplankton, are susceptible to increased acidity as their ability to make shells is inhibited or possibly reversed, dissolving their shells. Sea surface pH has dropped 0.1 pH units since the beginning of the Industrial Revolution [18].

Phytoplanktons are the most important biomass producers in the ocean. They are also a driving force for removing carbon dioxide from the atmosphere and transferring the carbon to other trophic levels. Declining populations will set off a domino effect with fewer krill and young fish leading to fewer numbers of seabirds and even death for seals and sea lions. Lowering of the phytoplankton populations will reduce the carbon dioxide absorbing capacity of the oceans.

Unfortunately, we cannot significantly increase the capacity of the oceans to sequester carbon. Proposed techniques for increasing ocean sequestration of carbon are in the experimental stages and have unknown long-term environmental consequences. Deep ocean injections of CO_2 are proposed, but this would move the problem from the shallow surface waters to the deeper waters where organisms are even more impacted by changes in their environment. Iron fertilization is another proposed idea in which iron added to surface waters would stimulate the growth of phytoplankton [19]. When these organisms and the organisms that eat them reach the end of their lifecycles and die, their bodies and the carbon inside them will leave the surface waters and fall to the deeper waters allowing more capacity for carbon sequestration to the surface layer.

Most models of the carbon cycle indicate that the land surface, vegetation and soils accumulate more carbon per year than they emit to the atmosphere, acting as a sink for CO_2. Land use is the largest uncertainty of any component in the overall carbon cycle. Even though deforestation releases more carbon than is captured by regrowth in some regions, net regrowth in other regions uptakes sufficient carbon so the land surface acts as a global net sink of approximately 1GtC per year. Approximately 50% of the terrestrial carbon sink stems (no pun intended!) from regrowth of forests on abandoned farmland. Woody encroachment, the increase of woody biomass occurring on grazing lands, is thought to be another large sink, possibly 20% [15].

The role of forests as potential carbon sinks is a priority for scientific research at present. The thought is that land use change in eastern deciduous forests has had a significant impact on the carbon cycle. They may have played a major role in the past carbon dioxide intake due to the regrowth following the major cutting at the turn of the previous century [20]. We will explore this concept on the local level through this unit.

Forest Management and Carbon Sequestration

Remote sensing data are not always accurate in their reflectance values on different land uses. This aerial view measures the dominant land cover of the highest canopy in woodlands. Canopy covers refer to the layers of the woodland vegetation. Multiple layers are normally present in woodlands. As a satellite passes over a site, it records the amount and wavelength of light reflected by all the vegetation it can see. In woodland sites like we will be working in, where there is space between the trees, there will be a contribution of reflectance values from the shrubs and the ground below the tree canopy, as well as the trees. Through the G.L.O.B.E. project, we are to ground truth: a 15 km by 15 km Landsat image of the Earth's surface surrounding our school. Using the modified UNESCO classification system, students determine the land use class for all of the types present in our image.

Students in the environmental landscape technology program must learn to do biometry measurements of woodlands. Biometry is the measuring of living things. The biometry measurements are of tree type, tree height, circumference, canopy cover, and ground cover. These types of measurements are important to understand the nature of a piece of land. Through these measurements, we can show the amount of nutrients and gases living things store. This includes the amount of carbon stored in trees.

Students will equate their biometry measurements to the amount of carbon that is being sequestering in the woodland at our school. These measurements will be ongoing throughout the unit in order to quantify, with relative accuracy, how much carbon typical woodlands can sequester.

Through this activity, students will be trained in a number of skills that are part of their task list. These skills apply the content students learn through lecture and readings and put them into action. Students will learn about orienteering and all the skills that go with that. This includes learning to become a human tape measure, through pacing, in order to estimate distances. They will also learn to properly use a compass. I guess there are very few Scouts anymore since I rarely meet a high school student that can use a compass. They will also learn how to use a builder's level in order to determine the slope of the site. These skills can be taught in a number of ways and I find that infusing them into a project like this one makes the students learn the skills while they determine the distances and elevations of the site.

Tree and plant identification is also a very important skill for my students to master. Looking at preserved leaves or reading keys will not get students to understand the principles of identification. This type of project challenges them to properly identify all of the trees to ensure that they return accurate results. We will focus just on leaves since that is the easiest way to identify trees. If you have not taught this topic before, here is just a brief intro and some basic information you should share with your students about using a dichotomous key to identify trees. I would recommend that you purchase some tree finder books for your classroom; they are very affordable and are easily used by students of all ages since they identify trees by using by using pictures to guide you.

To identify trees easily, look at their leaves. Trees have leaf characteristics that set them apart from other trees. Discuss the difference between evergreen and deciduous trees with the students; that should be easy, but do not forget broadleaf evergreens. Drawing pictures on the board or creating some overheads or a PowerPoint with photos will help them understand the concepts. Be sure you discuss the parts of the leaves so students have a working vocabulary before being introduced to dichotomous keys. Some of the more important leaf characteristics that need to be discussed are leaf arrangement, simple versus compound leaves, and leaf margin. Trees can have oppositely or alternately arranged leaves. Oppositely arranged leaves are positioned directly across from each other. Alternately arranged leaves alternate the sides of the branches as they grow down the branches. Simple leaves are composed of one leaflet, whereas, compound leaves are composed of many leaflets per petiole. Lastly, discuss the leaf margin (leaf edges) and the myriad of different margins that exist on plants. You should discuss smooth (entire), serrations/teeth (dentate), curves or projections (lobes), and any bristles that are included on the tips of the margin. If you have never used a dichotomous key, the Michigan state tree identification website will be very helpful to you and your students [21].

Effective analysis and proper experimental design are important skills of a scientist and are skills that should be taught in an environmental classroom. Through this biometry protocol, students divide up the woodland and define plots in which they will identify all the tree species present and determine their height and diameter a breast height (DBH). The measurements for height are determined by having students construct clinometers out of a grid, a piece of cardboard, a piece of string and a washer. The clinometer uses elementary trigonometry to determine the height and may be a great way to integrate with a teacher in your math department (more students to measure the trees, the quicker it will be done!). The diameter can be determined by using a Biltmore stick, which can be constructed by the students (good measurement activity), or a diameter tape. Fear not, data sheets used in the field for these protocols are downloadable from the G.L.O.B.E. website. Once the data in the field are collected, students will then input their data into an Excel spreadsheet. Having students input these data makes them appreciate the power of calculations and graphing of Excel. I like to infuse technology whenever possible; students need to see the application of software other than in their computer classes in high school.

I thought that determining the amount of carbon sequestered by trees may be a relatively easy task, but I will tell you that I read many articles from scientific journals on this and in fact it is one of the things current research is focusing on. Most look just at remote sensing data or overall area of a forest or woodland and equate the carbon sequestered to an acceptable value. Species specific sequestration is hard to find being studied but, I was fortunate enough to finally determine a way to equate the tree species and age to the amount of carbon sequestered. This will bring a great mathematics component to the unit and require students to really work, not only within their groups but, to share their information with the class as a whole. Tallying up field data and running statistics on the plots is a good exercise and will make them apply and reinforce a number of skills from the mathematics classroom.

Once students get a sequestration value to their studied piece of wooded property, they will then extrapolate their findings to other areas in their local environment. Students will use aerial photos of the county taken in 1998. Through aerial photo interpretation, students will determine local land areas that can sequester carbon. These areas are traced on vellum laid over the aerial photo and then calculated into the amount of area they cover. Students will convert their sequestration value to the same units and then determine the approximate amount of carbon the land on this aerial can sequester.

Using the data calculated on the number of cars used to commute in New Castle County and the carbon they emit, students can then determine the amount of wooded area needed in the county to offset these carbon emissions. Have students compare that to the actual value of wooded land in your county. I was able to get this number from a recent land-use study of our county. Have students analyze the differences between these two numbers and use the data collected through aerial interpretation to write a one-page letter to their local representative describing the problems associated with the difference in these values and what the county may be able to do to sequester this amount of emissions.

Students must also look at the trends of the land use to see if we are going in the right direction in the county. Students can use Google Earth to determine which areas that were there in 1998 are now converted to another type of use. My students are fascinated with using Google Earth and even if you do not feel that comfortable using it, they will catch on quick! I would encourage you to have them look at their own house first to become familiar with how to locate something using the software.

I have come to the realization through writing this unit that the only way we can sequester more carbon on the planet is through managing the terrestrial carbon sink much better. I am not sure how things in your neck of the woods are, but in Delaware all of our "wild" spaces seem to be turned into suburbia and the farms are now growing houses instead of crops for food or biofuels. This trend in land use equates to a diminishing amount of terrestrial carbon sinks in a time when we need to, not only preserve what we have but also, convert lands into ones conducive to carbon sequestration.

Presenting the Transportation Options

Have your student groups present their findings on their transportation fuel. Be sure the students in the audience help with the grading of the presentation by giving them a rubric on presentation skills. This allows all of the students to be engaged and analyze the art of speaking. This is an essential skill you need to help foster in your students and one that should be discussed after each presentation. I will also have a sheet with a few questions that I would like the students to glean the answers from each of the presentations. This ensures that they must listen to the presentation and they write down information with which they can use to think critically when engaged in conversation about the varied types of alternative fuels. Be sure to encourage lively debate and discussion after each of the presentations.

Sustainability is a word I did not use in this unit until this last section, but it is what we need to work towards with our transportation sector. Sustainable transportation will have to include a renewable fuel source to power vehicles. Sustainability to the transportation sector will also have to equate to a substantial decrease in the amount and kinds of pollutants that are emitted from the vehicles. We need to think in a different way in order to build a truly sustainable transportation system.

The internal combustion engine was an amazing innovation and revolutionized our whole existence. The wisdom of the continued burning of our limited supply of fossil fuels in them must be questioned. We are seeing exponential growth in fossil fuel usage in the last twenty plus years and auto fuel efficiency standards have changed very little in this time. It is no secret that burning these fuels has had devastating impacts on our environment. We are now looking to biofuels to help us work toward a carbon neutral transportation system that uses the internal combustion engine.

We need to take a long hard look at the efficiency of all of our transportation options. Internal combustion engines are around 10-15 percent efficient at burning fossil fuels. If you take into consideration the processing and transportation of the fossil fuels to the pump, the efficiency of the process is reduced significantly. Biofuels are dependent on a fossil fuel-based agricultural system to produce them. The efficiency of producing biofuels is very low, to the point where it is seen by many to not even be a net gain of energy if you factor in all aspects of production.

Electric vehicles have been introduced many times in the past but have been taken off the market. Automobile manufactures realize that these vehicles are efficient and do not need the liquid fuel infrastructure we currently use and they have very low maintenance costs.

Electric motors are about 90% efficient. The current production of electricity is also fossil fuel based but it does not have to be solely done in this manner. Advances in solar photovoltaic cells have occurred and they are around 16% efficient, while the efficiency of solar thermal electric generation is around 35% presently. If we were to move toward electric vehicles that were charged by solar energy, we would be able to achieve an overall efficiency of around 30%. This would be an amazing increase in the efficiency of this sector and also cause a dramatic decrease in the amount of carbon that is emitted.

Transportation needs to move away from the polluting and inefficient internal combustion engine and embrace the use of electric vehicles. This shift would dramatically increase the quality of our air, revitalize our soils, and give the water resources a better chance of buffering the effects of transportation used in our society.

Our society needs to have clean air, water, and soil in order to continue to survive on this planet. If we continue to use inefficient means of transportation and exploit our natural resources, we will continue to degrade and contaminate the very things we need most. We need to be reminded how delicate our existence really is. We can only live three weeks without nourishing and untainted food, three days without clean adequate water, and three minutes without oxygen. All of these three things are compromised as we continue using fossil fuels to power our transportation sector and our society.

Lessons

Unit Report on Alternative Energy Fuel for Transportation

Divide Students up into groups according to the fuels they are working on for this project. Students need to understand that the majority of this project is going to be focused on them learning about their particular fuel so they can convey the information effectively to the other students in the class.

The students should always have guiding questions to use when they are doing research. Depending upon the assignment, I will allow the group to draft their questions and submit them so that I know they have a clear idea as to what it is they are looking for. In this assignment, I am including questions for your students to use to get continuity to the end-unit project. You must realize that the students are going to give you exactly what you ask for, so you need to be sure you include everything you want when assigning these types of research tasks and be sure to factor all elements into the grade. The following is the actual sheet I am going to use with my students.

Your task is to develop a PowerPoint presentation to inform the public about your transportation fuel. This PowerPoint must not only be informative, it must be visually appealing and flow well so your viewer's interest is kept throughout. It should include pictures of vehicles that use the fuel, diagram listing the advantages and disadvantages of the fuel, and an environmental analysis of the fuel. You must insure that the PowerPoint presentation is constructed in such a way that everyone can understand the information conveyed, but at the same time it should be very informative so that the viewer feels as though they have a better understanding after the presentation.

The viewer should be able to answer the following questions from your PowerPoint presentation:

- What is the chemical composition of the fuel?
- Is the fuel renewable or nonrenewable?
- How is the fuel made?
- Is the fuel available in the local area?
- How does the fuel power a vehicle?
- What types of vehicles can use the fuel?
- What are the costs associated with the fuel?
- What are the economic advantages and disadvantages of the fuel?
- What are the environmental advantages and disadvantages of the fuel?
- What are the challenges to widespread use of the fuel?

Every person in your group will be required to take part in the presentation. Be sure to have the presentation practiced so that you are not simply reading the PowerPoint slides throughout the presentation. You must look at the people you are presenting the information to. The presentation must be 2-3 minutes in length per person in your group to get full credit.

Props and handouts are a great way to add interest to your presentation and will ensure that time minimum is attained. If you need some materials from the teacher, be sure to let the teacher know at least a few days in advance. Requests for materials the day of a presentation will not be granted.

Have fun with this assignment and use your creativity when making the PowerPoint presentation. Become an advocate for your fuel! Be sure you know your content; other students are encouraged to ask you questions and you should be able to give an intelligent answer to those questions if they are relevant to your topic.

Distillation of Simulated Crude Oil

This lab will require you to put together a distillation apparatus for each group of students. This will include a hotplate, an Erlenmeyer flask, two hole stopper, glass tubing, vinyl tubing, a condensation apparatus, and a small beakers to collect the condensate.

You will also have to mix up some simulated crude oil. This can be done by making a mixture of 20% methanol, 40% water, and 40% glycerin with a bit of calcium carbonate and a water-soluble black dye to make it look like oil. These are easily distilled since they have different boiling points. Just like in the fractional distillation of crude oil the temperature of the mixture rises and the different substances boil off at different temperatures. The condensation apparatus will then take the vapor and condense it back into a liquid.

Have students set up the distillation equipment and place a measured volume of the crude oil in the Erlenmeyer flask. The students need to distill this at medium heat to keep the liquid boiling slowly at all times during the distillation. Students collect three fractions during the distillation. The first fraction is collected from the starting point till the temperature reaches around 90 $^{\circ}$C, since methanol boils at about 65 $^{\circ}$C. The second fraction should be collected from the end point of the first until the temperature reaches 102 $^{\circ}$C, since water boils at 100 $^{\circ}$C. Once the fraction is collected at 102 $^{\circ}$C, you will need to have the students turn off the hotplate and use the flask as the last fraction, since the glycerin boils at 290 $^{\circ}$C. Be sure to allow the third fraction to cool thoroughly since it will be extremely hot! This distillation takes only about 20 minutes and it is very engaging for the students.

To analyze the fractions, you could do a number of things. A forensics twist to this is that you can make up molecular models of each of the three constituents in the mixture and have students identify them and their properties. You can then have the students determine the density of each of the fractions and then they have to identify which fraction is made up of the constituent and why, justifying their answers with such things as boiling points, densities, etc. You can even do some chemical testing, if you want to get even more involved with this lab.

Determining the Amount of Emissions Emitted by Local Commuter Vehicles

Using the data on the daily commute for people in New Castle County, DE, calculate the amount of emissions produced each workday.

To simplify your calculations, assume everyone's commute is 20 miles round trip.

Each vehicle type has an average fuel economy associated with it in the table below.

Determine the amount of gas needed to make the commute.

Determine the amount of CO_2 produced by each vehicle. It is understood that, for every gallon of gas burned in a motor vehicle, 20 lbs of CO_2 are produced.

(table 07.05.01.01 available in print form)

The percentages of vehicles used in both driving alone and carpooling during the commute are 42% cars, 31% light trucks / vans, and 27% SUVs.

Determine the number of each vehicle type that is on the road in New Castle County, DE during the commute and the amount of CO_2 that is produced by each vehicle type. You will need to look up the total number of vehicles driven during the commute each day.

(table 07.05.01.02 available in print form)

Due to incomplete combustion of motor vehicles, there are a number of pollutants produced during the commute.

To simplify your calculations, you will use the average amount of pollutants.

Determine the amount of pollutants produced by all the vehicles used in the commute.

It is understood that, for every mile the vehicles are driven, they produce 1.298 g of VOCs, 1.518 g of NOx, and 8.659 g CO.

(table 07.05.01.03 available in print form)

Determining the Amount of Carbon Sequestered by a Woodland

Students will engage in running the G.L.O.B.E. biometry protocol on our campus woodland. Once students have determined the type and amount and approximate ages of the trees in the woodland, they then will do the calculations to determine the amount of carbon sequestered by these trees. The ideal area would be a 30 meter by 30 meter wooded area to run the tests in. This protocol can also be done for only a couple of trees, if that is all you have near your campus.

The amount of carbon sequestered depends upon the tree type and the age of the tree [22]. Have students construct the following spreadsheet to determine the sequestration value for the woodland they analyzed.

(table 07.05.01.04 available in print form)

The sum of all the values for the last column in the spreadsheet will be the amount of carbon the woodland will sequester annually.

Once students have determined the amount of carbon sequestered annually, they then need to change their answer from lbs/yr/30 m^2 to how many lbs/yr/ft^2 to be used when extrapolating to the amount of carbon sequestered by the other wooded areas in the county. Distances in these photographs are based in feet and calculating area on these photographs will come out to ft ^{2} . You should have the students figure out this conversion. It is amazing how few students get the opportunity to convert measurement between units. This is a very good skill to teach your students. They need to be able to use conversion factors to determine the proper amounts of many things in their lives on the job and at home.

Students will use an aerial photograph to determine all the wooded areas and trace them on vellum. The area in square feet of each of these areas is calculated. The sum of all the areas is then determined. They can then determine the carbon sequestration capacity of the land in the aerial.

I would then have students do the following calculation assignment and write a letter to their local representative explaining and describing the problems associated with the difference in the values of CO_2 produced by commuter vehicles and CO_2 sequestered in wooded areas and what the county may be able to do to increase sequestration of emissions.

According to the Delaware Office of State Planning coordination, New Castle County currently has 43,888.72 acres of forested land. This number reflects an almost 6% reduction in forested lands in just five years.

Using your calculations, how much carbon can the county's forest resources sequester annually?

Looking at your results from the amount of carbon that is produced by the commuter vehicles in New Castle County, do the forest resources offset the proper amount of carbon just for our transportation emissions?

Student Resource Binder Articles

This is by no means a large sampling of articles out there. I was able to acquire many more articles to place in student resource binders; the citations for all would not fit in this section due to space requirements for this unit.

Blottnitz, H., & Curran, M. (2007). A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. *Journal of Cleaner Production*, 607-619.

Bossel, U. (2006). Does a Hydrogen Economy Make Sense? *Proceedings of the IEEE*, *94*, 1826-1837.

Chalk, S., & Miller, J. F. (2006). Key challenges and recent progress in batteries, fuel cells, and hydrogen storage for clean energy systems. *Journal of Power Sources*, *159*, 73-80.

Demirbas, M. F., & Balat, M. (2006). Recent advances on the production and utilization trends of bio-fuels: A global perspective. *Energy Conversion and Management*, 2371-2381.

Ethanol for transportation. (2002). *Issues in Science and Technology*, *18*.

Karner, D., & Francfort, J. (2006). US Department of Energy Hybrid Electric Vehicle Battery and Fuel Economy Testing. *Journal of Power Sources*, 1173-1177.

Lund, H., & Munster, E. (2006). Integrated transportation and energy sector CO_2 emission control strategies. *Transport Policy*, *13*, 426-433.

Malca, J., & Freire, F. (2006). Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): Assessing the implications of allocation. *Energy*, 3362-3380.

Mierlo, J. V., & Maggetto, G. (2007). Fuel Cell OR Battery: Electric cars are the Future. *Fuel Cells*, *07*, 165-173.

Petrus, L., & Noordermeer, M. (2006). Biomass to biofuels, a chemical perspective. *Green Chemistry*, 861-867.

Polasky, S., Tilman, D., Hill, J., Nelson, E., & Tiffany, D. (2006). Environmental, economic and energetic costs and benefits of biodiesel and ethanol biofuels. *PNAS*, *103*, 11206-11210.

Rahman, S., & Andrews, C. (2006). Special Issue on the Hydrogen Economy. *Proceedings of the IEEE*, *94*, 1781-1784.

Solli, C., Stromman, A. H., & Hertwich, E. G. (2006). Fission or Fossil: Life Cycle Assessment of Hydrogen Production. *Proceedings of the IEEE*, *94*, 1785-1794.

Wu, M., Wu, Y., & Wang, M. (2006). Energy and emission benefits of alternative transportation liquid fuels derived from switchgrass: a fuel cycle assessment. *Biotechnology Prog.*, *22*, 1012-1024.

Yeh, S., Loughlin, D., Shay, C., & Gage, C. (2006). An integrated assessment of the Impacts of Hydrogen Economy on Transportation, Energy Use, and Air Emissions. *Proceedings of the IEEE*, *94*, 1838-1851.

Bibliography / Teacher Content and Teaching Resources

[1] Gore, A. (2006). *An inconvenient truth the planetary emergency of global warming and what we can do about it*. Emmaus, Pa: Rodale Press.

Excellent reading for the students and the teacher. It is like a picture book on global warming for grown-ups!

[2] *ChemCom*. (1993). Dubuque, Iowa: Kendall/Hunt Pub. Co.

Textbook that has a number of great units within it. It makes chemistry relevant to student's lives.

[3] *Science and Sustainability*. (2001). Ronkonkoma, NY: Lab Aids, Inc.

Another textbook that makes science relevant to students' lives and serves as a great curriculum package for an integrated science class.

[4] http://www.ioga.com/Special/PetroProducts.htm

The most complete list of products made from petroleum on the web!

[5] Amann, C. A. 1989. The automotive spark-ignition engine—An historical perspective. In History of the Internal Combustion Engine, ICE, Volume 8, Book No. 100294-1989, E. F. C. Somerscales and A. A. Zagotta, eds. American Society of Mechanical Engineers.

[6] Mierlo, J. V., & Maggetto, G. (2007). Fuel Cell or Battery: Electric cars are the Future. *Fuel Cells*, *07*, 165-173.

Definitely read this article! It is amazing to think that we do not use electric vehicles.

[7] Scripps Institution of Oceanography. (2007). How do we know that CO_2 is increasing in the atmosphere? Retrieved July 5, 2007 from http://scrippsco2.ucsd.edu/faq/faq.html

[8] *How Can We Reduce Air Pollution* (2001). New York: W. W. Norton & Co. Retrieved from http://chemlinks.beloit.edu

An undergraduate chemistry curriculum you can download. This module looks at the chemistry of automobile pollution and the oxygenation of gasoline to reduce emissions.

[9] http://www.city-data.com/

This website will give you all the facts you would want to know about your city.

[10] http://www.grida.no/climate/ipcc_tar/wg1/index.htm

Intergovernmental Panel on Climate Change Climate Change 2001: The Scientific Basis

[11] Houghton, R,A.(2007). Balancing the global carbon budget. *Annual Review of Earth and Planetary Sciences, 35,* 313-347. Retrieved July 3, 2007, from Social Science Library database.

[12] Schlesinger, W. H. (1997). *Biogeochemistry an analysis of global change*. San Diego, CA: Academic Press.

This book is written to look at how the biogeochemical cycles are being effected with global warming.

[13] *WMO Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Using Global Observations through 2005* (Publication No. 2). (2006). Geneva: World Data Centre for Greenhouse gases (WDCGG).

at http://gaw.kishou.go.jp/wdcgg.html

[14] Sarmiento, J., & Gruber, N. (2002). Sinks for Anthropogenic Carbon. *Physics Today*, 30-36.

Article talks about the potential for all the different sinks to uptake carbon from human uses of fossil fuels.

[15] IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

A very complete abstract of the new IPCC report that is in the hundreds of pages. This is useful in looking at what scientists around the globe are saying about the upset of the carbon cycle and what this may mean in terms of climate change.

[16] Field, C. B., & Raupach, M. R. (2004). *The global carbon cycle integrating humans, climate, and the natural world*. Washington: Island Press.

This book looks at the global carbon cycle and quantifies the amount of flux between all aspects of the environment as well as the anthropogenic inputs.

[17] Archer, D. (1998). Dynamics of Fossil Fuel CO_2 Neutralization by Marine $CaCO_3$. *Global Biogeochemical Cycles*, *12*, 259-276.

Discusses the amount of CO_2 from fossil fuels and how it is sequestered by the oceans and possible effects on ocean chemistry and life.

[18] Calderia, K. (2005). *Ocean acidification due to increasing atmospheric carbon dioxide* (Rep.). London: The Royal Society. at http://www.royalsoc.ac.uk

Discusses the ocean chemistry and the effects ocean acidification may have.

[19] Blain, S. (2007). Effect of natural iron fertilization on carbon sequestration in the southern ocean. *Nature*, *446*, 1070-1074.

A study in which iron filings were dumped into the ocean to attempt to improve ocean carbon sequestration.

[20] Stephens, B. (2007). Weak northern and strong tropical land carbon uptake from vertical profiles of atmospheric CO_2. *Science*, *316*, 1732-1735.

Discusses the importance carbon intake of forests in both tropical and temperate regions.

[21] http://forestry.msu.edu/extension/ExtDocs/idents.htm

Website will help your students master the art of using a dichotomous key

[22] U.S. Department of Energy, Energy Information Administration. (1998, April). Voluntary reporting of greenhouse gases. In ***Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings***. Retrieved July 9, 2007 ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/sequester.pdf

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