Curriculum Units by Fellows of the National Initiative
2007 Volume V: Renewable Energy

Solar energy: Using Carbon Dioxide from the Atmosphere to Produce a Viable Fuel Source

Curriculum Unit 07.05.02, published September 2007
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Introduction

In the time of dire predictions about the effect of global warming, there are many questions that we need to ask about renewable technologies. Which technology can actually shift our carbon based economy to one that does not increase carbon dioxide in the environment? How will we meet our energy demands, and do we actually have the technology to do so?

Renewable energy includes fuels that are not "used up" or those that are naturally replenished. The most common renewable energy sources include solar energy, wind power, hydroelectric, biomass, geothermal and tidal power. Many of us who are concerned about our fossil fuel economy have hopes that renewable energy is a viable solution to our energy and climate problem. Yet, how feasible is it that renewable energies will replace fossil fuels as our primary energy source?

In 2006, renewable energy provided 6.85% of the total energy consumption in the United States [1]. Among the renewables, solar accounts for 0.07%, wind 0.26%, hydroelectric 2.89%, biomass 3.28%, and geothermal 0.35% of total energy use. The remainder was provided by nuclear power (8.2%) and fossil fuels (84.8%: coal and coke 22.6%, natural gas 22.4% and petroleum 39.8%). Since the 1980s, the proportion of total energy consumption provided by renewables has varied from a low of 5.5% in 2001 to a high of 8.9% in 1983. While the total amount of energy produced by renewable sources has increased since 1980, the proportion of renewables is smaller now because of the rise of nuclear power after the 1973 oil embargo [2].

Energy consumption is measured in several different units, in British Thermal Units (BTUs), as well as joules (kilojoules and mega joules), watts (kilowatts, megawatts and terawatts) and calories (kilocalories) [3]. I will use terawatts (TW), as used by Nate Lewis of California in his presentations and publications about global energy use. The world's total demand for energy in 2000 was 13 terawatts (TW), equivalent to 10^{12} watts. Of this total, the U.S. consumes approximately one-fourth; 3.3 TW in 1998. In 2005, world demand was 16.5 TW, and it is projected that world energy demand will be 28 TW by 2050 [4].

Because coal, oil and natural gas prices remain low compared to renewables, a financial incentive to switch to renewable sources of energy does not exist [5]. However, the incentive to shift to renewable energy sources is the profound evidence of global warming and predictions for future catastrophic changes, among them significant sea-level rise, desertification, and the loss of numerous plant and animal species. It is predicted that the atmospheric CO_2 concentration, which has historically been 300 parts per million (ppm) or less, will be 750 ppm or more by 2050, according to the "business as usual" model presented by the International Panel on Climate Change (IPCC). To stabilize the carbon dioxide concentration of the atmosphere at 550 ppm, 20 of the 28 TW predicted to be used in 2050 should be produced using renewable energy [4].

What is the potential producing power of the renewable resources? Nuclear power could potentially contribute to the carbon-free energy demand, though it remains controversial because of the large amount of radioactive waste produced. To produce 10 TW of power, 10,000 1-gigawatt (GW) power plants would need to be built, which is more than 200 power plants per year for the next 50 years. Hydropower, while a very clean source of energy, cannot provide energy on a large scale. The power generating potential of every river, lake and stream on the planet is only 4.6 TW. Because most of the large rivers already have power generating dams in place, there is not considerable opportunity to increase the amount of power generated by hydropower, except on a small scale for local power production. Windpower has a potential generating power of 2 TW terrestrially, yet a considerable amount more if wind farms could be located in the oceans. At this time, the technology and efficiency for storing and transporting this energy does not make ocean wind farms a viable option [4].

Solar energy holds the greatest potential for replacing fossil fuels as our primary energy source, according to Nathan Lewis, Chemistry professor at the California Institute of Technology [4]. Enough energy from the sun strikes the Earth in one hour to supply all the energy consumed by humans in an entire year [5]. Based on this prediction, I chose to study a component of solar energy in depth, specifically the solar energy that is stored in plants and converted into the biofuels, ethanol and biodiesel.

My curriculum unit will focus on the biological sources of solar energy including biomass, which is burned (wood) or converted into fuel that can be burned (ethanol, biodiesel). Non-biological sources of solar energy are the rays of solar radiation that can be used passively to heat homes and water, or the rays that are collected by photovoltaic cells and stored to provide electricity. Both types of solar energy are renewable energy resources, and while they are only used in limited capacities currently, they have the potential to replace our fossil fuels in the future. Unfortunately, we have been accustomed to using coal, oil and gasoline for so long that many in our society, including our government, have an inability to envision a successful economy driven by renewable technology.

Biomass, in the form of ethanol and biodiesel, has recently received attention, even though burning of wood is an extremely old practice as is the fermentation of plants into alcoholic beverages. The energy stored in biomass is a result of solar energy, specifically a product of photosynthesis. While biomass is seen as a renewable technology, use of biomass instead of fossil fuels is not always a benefit to the environment. Burning or combustion of these materials does release greenhouse gases, but these effects can be reduced if biomass is used in certain ways.

Which biofuel is the best? Studies have shown that biodiesel has a considerably higher net energy gain than ethanol, though ethanol appears more widely used in the United States [6]. The rationale for usage of one fuel rather than the other appears to be directly related to politics and economics, with tremendous potential impacts on farmers and the food supply.

Rationale

Teaching students about renewable energy is crucial to help them see the potential of these energies in their lives. Global warming has gained dramatic attention in the last few years, and students are becoming more aware of the problem. Students also know some ways that they can help, recycling and conserving electricity, for example. However, many students are looking to their parents, teachers and schools as examples of how to fix the climate problem. While we now acknowledge the problem, we are not effectively doing enough to solve it. We are giving our students mixed signals, and some feel that we are leaving the climate problem up to them.

Teaching about solar energy interests me because it is an interdisciplinary concept. My unit will cross disciplines, including biology, chemistry, environmental science and physics principles. Teaching a topic in this way will help students see the connections between chemical bonds and energy and food in a new way. My unit will also bring in politics, economics, and sociology to understand why our country is making the laws and decisions that we make. By studying all aspects surrounding solar energy, my students can understand the barriers and complexity of transitioning from a fossil fuel to a renewable energy-based economy.

I will be teaching this entire unit with my Environmental Science classes, which encompass students from 9th-12th grade. I will also teach portions of this unit to my freshman Biology classes. My students have a wide range of abilities ranging from below grade level to gifted. These students also have a wide range of prior knowledge and interest in the Environmental Sciences. Throughout this unit, students will be challenged with varied topics as astronomy, biochemistry and electricity, but students that have more difficulty with these concepts can find an easier time with the writing and creative aspects of the unit.

As a philosophy of our school, we, as teachers, encourage our students to see themselves as leaders and contributing members of their communities. These students need to have an awareness of current issues as well as a desire to bring about change and progress. Students need to have knowledge and experience with the new renewable technologies so that they will be more likely to incorporate these technologies into their lives and develop possible career interests in these fields.

Objectives

My objective for this unit is to expand my students' knowledge and understanding about renewable energy sources. Students will focus on the contribution of solar energy, primarily in the form of biomass, to our current and future energy demand.

Students will learn about the energy that comes from the sun, which enters the atmosphere and is used by plants in photosynthesis. They will study the carbon cycle, tracing the carbon dioxide that is taken from the atmosphere, assimilated into plants which are used as fuels, and then released back into the atmosphere. Students will research possible ways that photosynthesis can be used in new ways to remove, or sequester, carbon out of the atmosphere in the future.

Students will focus on the contribution of biofuels, ethanol and biodiesel, studying the costs and benefits and unintended social and economic problems associated with each. With a solid background in carbon emissions and renewable energy sources, students will analyze their own carbon dioxide contribution and propose ways to reduce their impact on the environment. They will share the information found with their families and devise a plan to reduce emissions and save money immediately through conservation and energy saving strategies. Throughout the unit, students will see that we will need a combination of the renewable energies to replace our dependence on fossil fuels, though solar energy has the greatest potential for fulfilling our needs.

Background Knowledge

The Sun

The Sun is 90 million miles from the Earth, yet despite this unfathomable distance, the Earth's surface receives a huge amount of energy from the Sun. This energy, also known as electromagnetic radiation, is formed by nuclear fusion, in which hydrogen atoms fuse producing helium due to the extremely high temperatures in the Sun. The electromagnetic spectrum ranges from long wavelength, low frequency radio waves to short wavelength, high frequency gamma rays. The Earth's atmosphere only allows some of this radiation to reach the surface though. A narrow band of this spectrum that can pass through the atmosphere is known as the visible spectrum, or the photosynthetically active radiation [7]. Depending on your location in the globe, between 105 kW/m^2 (in England) to 1000 kW/m^2 (at the equator) of energy reaches the Earth's surface. One kilowatt can power a 100 Watt lamp for 10 hours, a laptop for 24 hours, or a vacuum cleaner for 45 minutes [8].

Carbon

Carbon is the sixth most abundant element on Earth, but it is one of the most important because it is found in every organic molecule. Carbon can bond with many different elements including itself, and, thus, there are a myriad of molecules that carbon can form. Carbon has four valence electrons, thus each carbon atom will form covalent bonds with up to four other atoms, in order to become stable with eight electrons in the outer shell. Carbon can form various inorganic compounds, such as carbon dioxide, carbon monoxide, and carbonates. Organic molecules are those containing carbon bonded to hydrogen, with other atoms as well. These include fatty acids, alcohols, proteins, carbohydrates, nucleic acids and polymers like plastic.

Related Activities:

It's All About Carbon Episodes 1-5, http://www.npr.org/news/specials/climate/video/

The Carbon Cycle

The carbon cycle explains how carbon moves through ecosystems changing in state and molecular form. The carbon cycle includes two parts. The geological carbon cycle involves long-term weathering, subduction and volcanism. Carbon dioxide dissolves in the oceans to form carbonic acid, which then reacts with calcium and magnesium in the crust to form insoluble carbonates which settle out. The deposition of carbonates and weathering of rocks from the crust provide a source of carbon that is taken into the mantle through subduction. This carbon is released back into the atmosphere from the eruption of volcanoes [9].

The biological carbon cycle involves the movement of carbon through organisms on land and in water through photosynthesis and respiration. Photosynthesis, which is described in the next section, is done by autotrophs by using the energy from light to split water and incorporate hydrogen atoms into carbon dioxide, making a carbohydrate like glucose ($C_6H_{12}O_6$). The energy stored in carbohydrates is then released by all organisms during respiration. In this process, carbohydrate is burned in the presence of oxygen, and water and carbon dioxide are produced and released back into the atmosphere. The amount of carbon cycled though these biological processes are 1000 times greater than the geological aspect of the carbon cycle [9].

Carbon that is taken in during photosynthesis can be stored for long periods of time in plants, for example in the trunk of a tree. This carbon is released back into the atmosphere as carbon dioxide when the tree dies, or is cut, burned, or decayed. Additionally, carbon is released by plants or trees during respiration. Actively growing trees assimilate more carbon dioxide than is released by respiration, though mature trees reach a point of carbon saturation produce as much carbon dioxide in respiration and decay as is removed from the atmosphere by photosynthesis [10].

Related Activities:

Carbon Neutral Cars? - see Activity #2 in Resources

Photosynthesis

Photosynthesis is the process in which solar energy is converted to chemical energy. In other words, the energy in light is used to convert CO_2 and H_2O into $C_6H_{12}O_6$ and O_2. This process occurs in two steps, the light reactions (which requires light) and carbon fixation (also known as the dark reactions or Calvin cycle). In the first step of photosynthesis, the light energy from the sun is used to split water, which results in the release of oxygen and the production of hydrogen ions and free electrons. The hydrogen ions and electrons continue to the second step of photosynthesis in which carbon dioxide is reduced by hydrogen and electrons to form a carbohydrate like glucose.

In *Energy, Plants and Man*, David Walker gives numerous anecdotes which illuminate early discoveries about photosynthesis. For example, a scientist, named Van Helmont, planted a willow tree in a tub with soil that he had weighed. He watered the willow tree for five years after which time the willow weighed 164 lbs greater and the soil only two ounces less. Van Helmont concluded that the tree had grown in size because of the water. He also concluded that the difference is soil mass was an error (Walker, 1992). This example is excellent at confronting misconceptions that many students may have. Fertilizers, which contain essential nutrients N (nitrogen), P (phosphorous), and K (potassium) are important cofactors in plant growth, much like vitamins are to a human diet. But fertilizers alone do not result in plant growth. The gas in the atmosphere (carbon dioxide) and the water in the presence of light produce glucose molecules, which combine to form larger molecules like starch and cellulose. Cellulose forms the framework of plant structure, and starch provides storage for glucose, from which the plant can depend on during times of reduced photosynthesis [11].

Almost all of the energy on the Earth originates from the Sun and is made accessible to humans through photosynthesis. Plants are able to use light energy in a way that humans are trying to replicate. Plants absorb light from the Sun using pigments, primarily chlorophyll a, chlorophyll b and caroteniods. These pigments absorb slightly different wavelengths of light; for example, chlorophyll a absorbs red and blue light best, reflecting green light which makes plants appear green. Chlorophylls are found in chloroplasts, cell organelles which are numerous in photosynthesizing plant cells. Chloroplasts contain many compartments, called thylakoids that are surrounded by membranes. The compartments allow multiple chemical reactions to take place simultaneously. Chlorophylls and other pigments are found in embedded in the thylakoid membranes. The matrix that surrounds the thylakoids is called the stroma. These two distinct locations are where the two steps of the photosynthesis reaction take place [11].

The first step of photosynthesis, using light to split water, occurs in two photosystems, which are protein complexes within the thylakoid membrane of a chloroplast. When light strikes a leaf, the light energy is initially harnessed by antennae (which consist of 500-1000 pigment molecules) found within Photosystem 2 (PS2). The antennae pigments funnel energy to a chlorophyll molecule in a reaction center, which is elevated to an excited state. In the excited state, an electron of the chlorophyll molecule is moved to an energy level that is farther away from the nucleus. These elevated electrons are quickly transferred to small electron accepter molecules, which are alternatively reduced and then oxidized as electrons move through the electron transport chain (ETC). This movement of electrons can be thought of as "downhill" movement- electrons moving toward progressively more electron attracting molecules, releasing small amounts of energy at every step. The energy is used to pump (through active transport) hydrogen ions across the thylakoid membrane into the thylakoid (lumen) against the hydrogen ion concentration gradient. The positive charges in the lumen create a proton gradient, an imbalance of charges on either side of the membrane. This proton gradient is a source of potential energy which is used along with the enzyme ATP synthase to produce ATP from ADP. The energy in the form of ATP is used in the carbon fixing reaction in the stroma [11].

The electron moves along the electron transport chain towards Photosystem 1 (PS1), which also captures light using antennae and a reaction center. The energy from the light captured in PS1 is used to kick up the electron to a further excited state. The electron is again carried through an electron transport chain to its final electron acceptor, NADP (nicotinamid adenosine dinucleotide phosphate). $NADP^+$ becomes NADPH when it receives a hydrogen ion and two electrons from the ETC of PS1. NADPH along with energy (ATP) that is made during the light-dependent reactions is used in the second part of photosynthesis, in which CO_2 is reduced, forming a carbohydrate like glucose [11,12].

The reduction of carbon dioxide is also known as the dark reactions. This name is a misnomer, because while these reactions do not require light, they occur in the light [11]. It is convenient to separate this set of reactions from the light reactions (water oxidation reactions) because the light reactions produce energy and occur in the thylakoid membrane and lumen, while the dark reactions use up the energy produced in the light reactions and occur outside the thylakoid, in the stroma. The energy in ATP and electrons in NADPH are used in this process which begins with a 5 Carbon sugar phosphate molecule accepting CO_2 in the presence of the enzyme rubisco. Rubisco is extremely abundant in the stroma of a chloroplast, and is, in fact, the most abundant protein on Earth. The 5C sugar and CO_2 combine to form a 6 C sugar which immediately splits into 2 3C molecules. These molecules undergo phosphorylation (by ATP) and reduction (by NADPH) to regenerate the initial 5C sugar and to produce a carbohydrate that will undergo further processing to form glucose. Glucose may be the final product or it could undergo processing to form sucrose (a disaccharide) or starch (a polysaccharide), for example [11].

Related Activities:

Paper Chromatography - http://www.ekcsk12.org/science/lelab/chromatographylab.html, http://www.ekcsk12.org/science/aplabreview/chromatographylab.htm

Starch Pictures - http://www.accessexcellence.org/AE/AEC/AEF/1996/morishita_pictures.html

Biomass: Ethanol vs. Biodiesel

Biomass includes any plant or plant-derived material that was originally the result of photosynthesis [13]. Biomass has been used throughout history, primarily as wood or dung. Recently, scientists have been using plants and plant remains to produce fuel rather than to produce heat or make electricity. What are the benefits of fuel over electricity? Making fuels from plants is precisely what fossil fuels are; though fuels from biomass can be produced in minutes rather than in millions of years.

Biomass does emit carbon dioxide when it is burned. This amount is offset by the carbon dioxide that the plant took in through photosynthesis as it was growing. The plants that formed fossil fuels died millions of years ago and, thus, are no longer photosynthesizing, only releasing carbon dioxide as they are burned. So, biomass is a good alternative to fossil fuels, but, even as a carbon neutral fuel, (photosynthesis balanced by respiration) biomass fuel does not reduce the amount of carbon dioxide in our atmosphere, it merely does not increase the amount. In addition, the production of biomass incurs hidden carbon dioxide costs. For example, the fuel required by tractors, fertilizers, trucks and machinery to grow, transport and produce the biofuel needs to be included in the carbon dioxide equation.

The two major types of biofuels on the market today are ethanol and biodiesel. Ethanol is an alcohol-based fuel that is made by fermenting the glucose in starch from wheat, barley and primarily corn. It can also be made from sucrose found in sugar cane. The Clean Air Act of 1990 mandated the gasoline be oxygenated in order to reduce the carbon monoxide emissions. Ethanol and methyl tertiary-butyl ether (MTBE) were the two additives used for this purpose, though MTBE use has been discontinued because it was found to contaminate ground water. Ethanol is blended with gasoline is various percentages; commonly 10% which reduces emissions and improves the octane rating. Higher blends of ethanol include Ethanol 85 (85% ethanol and 15% gasoline) and Ethanol 95. These blends are considered alternative fuels and can be used in flexible fuel vehicles (FFVs). The use of ethanol is advantageous to the U.S. because it reduces our demand of oil from other countries, and ethanol use supports U.S. farmers, primarily in the Midwest. There are drawbacks to ethanol use, however. Ethanol contains less energy than gasoline, which results in lower mileage per gallon of fuel [14].

The rise of ethanol to replace MTBE as a gasoline oxygenate has been controversial because some researchers concluded that producing ethanol resulted in a limited gain or even a net loss of energy [15]. One reason for the relative uncertainty is that ethanol can be produced by various types of plants, parts of plants and using different processes. For example, ethanol is largely produced from corn in the U.S. and from sugarcane in Brazil. Further, ethanol is the U.S. is made by converting the starch which is found in the corn kernel, while ethanol in Brazil is made using sucrose which is found in sugarcane.

Ethanol is produced from sugar or starch by dry-mill or wet-mill processing [16]. In dry-mill processing, the corn kernel is ground and then mixed with water to form a mash. Enzymes are added to convert the starch to dextrose, and the mixture is heated to kill-off bacteria before fermentation begins. The mash is cooled and yeast is added to begin the fermentation process, which takes 40-50 hours. The ethanol is separated from the stillage, and then concentrated to 200 proof using distillation and a molecular sieve. A denaturant is added to the ethanol to make it undrinkable, and it is then ready from shipment. The remaining stillage is processed further to produce a nutritious livestock feed. Wet-mill processing uses water and sulfuric acid to break down the grain into fiber, starch, corn germ, corn gluten and corn oil. The starch can be further processed into ethanol and the by-products sold or processed for livestock feed. Most ethanol (82%) is made using the dry-mill technique [16].

Biodiesel is a fuel that is primarily made from soybean oil. It is sold primarily in blends of B2 (2% biodiesel, 98% diesel) or B5 (5% biodiesel, 95% diesel). Higher blends of biodiesel (20%) are given credits through the Energy Policy Act of 1992. The benefits of biodiesel include reduced carbon dioxide emissions and displacement of imported petroleum [17].

Biodiesel is made from vegetable oil, which consists of triglyceride molecules, each with a glycerol head and fatty acid tails. Methanol and sodium hydroxide are combined together and added to vegetable oil that has been heated to 100-120 deg F. The mixture is stirred and then allowed to separate. During agitation, the sodium hydroxide reacts with methanol removing a hydrogen, which produces water and methyl oxide. The methyl oxide removes the glycerol head from the triglycerides and replaces glycerol with H_3C groups [18]. The resulting molecule is biodiesel, and glycerin is produced in small amounts as a waste product. After the biodiesel and glycerin separate, the biodiesel is washed with water to remove any remaining methanol which is corrosive. The reaction produces a very high yield, 1000 g of biodiesel for 1030 g of vegetable oil added [19].

Comparisons of the net energy gain of ethanol and biodiesel have been numerous [6,15, 20]. Simply, the amount of energy that it takes to produce ethanol must not be greater than the amount of energy that results. Some studies found a net loss of energy in ethanol production, yet later research criticized these studies for not including the co-products that result from ethanol production, like animal feed, that diverts energy use. Other studies have been faulted for expanding the boundaries of energy inputs to include the manufacture of farm equipment and buildings. Despite varied methodologies, the consensus is that ethanol and biodiesel do provide a net energy gain and a net reduction of greenhouse gases (GHG) over an equal volume of gasoline [6,20]. Factors that serve to reduce this net energy gain includes the production and application of fertilizers, both of which consume petroleum, in addition to the transport of the crop to the production plant and transport of the fuel to the retailer.

Researchers compared ethanol and biodiesel using four standards: net energy gain, environmental effects, economic cost, and capability for growth without negative impact on food production. For net energy gain, biodiesel provides 93% more energy required for its productions, while ethanol provides only 25% more energy than is input. Biodiesel reduced GHGs by 41% compared to diesel and ethanol only provides a 12% decrease. Biodiesel results in a reduction in four of the major emissions including VOCs (volatile organic carbons), CO, Sox (sulfur oxides) and large particulate matter (PM 10, diameter>10 mm). Low-level ethanol-gasoline blends (for ex. 10%) reduce CO, VOCs and particulates during combustion, though ethanol 85 has higher levels of CO, VOC, PM10, SO_x, and NO_x than an amount of gasoline with the equivalent energy content.

Further, corn requires greater amounts of fertilizer (N and P) and pesticides than soybeans. Neither fuel is economically competitive at this writing with gasoline or diesel without subsidy [6]. Current agricultural practices contribute to GHG emissions (34-44%) and petroleum inputs (45-80%) associated with the ethanol [20]. Improvements in the agriculture industry, could significantly improve the net energy gain and environmental impact of ethanol. For example, conservation tillage can reduce soil erosion, fertilizer and pesticide runoff, as well as petroleum use and GHG emissions.

Further ways to improve the net energy gain and reduce GHG emissions of ethanol involve cellulosic technology. Currently in the U.S., ethanol is made from the starch in the corn kernel, while the husk and stalk remain unusable. Researchers are beginning to work on making biofuel from cellulose, which will allow biofuel to be produced from corn waste (the stalk and husk) and many other plant wastes. This process is currently being developed in pilot programs and in selected areas. The conversion of cellulose into ethanol holds great promise for economic and environmental reasons. Cellulosic technology does not interfere with food production, as corn and soybean conversion does. Plants such as switch grass can be growth in marginally productive areas with little or no fertilizer requirements. Combustion of waste biomass could be used to power the ethanol processing plants. Initial inputs of energy will be required for building these new production plants, and transportation costs may be higher for transporting waste biomass to the production plants. New developments in this technology promise to increase the net energy gain of ethanol and reduce the GHG emissions of the fuel [6].

Related Activities:

Making Biodiesel - http://journeytoforever.org/biodiesel_make.html
http://www.biodieselcommunity.org/gettingstarted/

Social and Economic Issues

Beyond the costs of fertilizer and transportation costs of producing biofuels, it appears there are more hidden costs associated with biofuel production. Because of the high demand for ethanol, international corn prices have increased dramatically. The result in Mexico is that prices of tortillas have tripled or quadrupled since the summer of 2006. A cap on tortilla prices has done little to alleviate vendors and consumers who are struggling to survive. Tortillas are a vital part of the Mexican diet, providing 40% of the protein, fiber and essential nutrients, like calcium. Poor Mexicans have been forced to shift their diet to other foods, among them, instant noodles which are far less nutritious. Corn shortages have forced Mexico to import 800,000 tons of corn from the U.S. in 2007, whereas corn was exported the previous year [21].

Soybean production in other countries is also reportedly wreaking havoc on human and ecosystem health. In Paraguay, the number of acres of soy jumped over 200% from 1999 to 2004. The expansion of soy has come at the expense of savanna and rainforest lands. Further, pesticide use, more than 24 million liters every year, has caused increased birth defects and reduced sperm count in exposed males. Paraguayans maintain that wildlife and livestock have died, forcing many to leave their lands. Cheap land in Paraguay brought soy farmers eager to satisfy the demand for biodiesel [22]. Estimates that consider biodiesel production to be a substantial net energy gain and GHG reduction are only valid if the soy is grown on land already in production. Clearing intact forest land to grow soy for biodiesel would likely contribute a net GHG release into the atmosphere [6].

New Technology

Artificial photosynthesis is renewable energy research area that may serve as a means for sequestering carbon dioxide from the atmosphere, thus reducing the amount of heat that is trapped by the Earth's atmosphere. There are many new technologies on the horizon, which could help reduce our oil consumption and carbon emissions. Many of these new technologies, including high altitude wind, tidal power, nanotech solar cells, and designer microbes, though, require time and substantial financial investments [23].

Scientists are actively working on the concept of artificial photosynthesis, and there seems to be two general approaches. One is to use a molecular assembly linking electron donors and electron acceptors. Light stimulates an electron to reach an excited state, and much like in the photosystems in plants, the electron moves to an electron acceptor. The main obstacle for this method is the tendency of the electron to quickly fall back to the electron donor. New carbon nanotube technology may help pull electrons away from donors quickly enough to ensure charge separation [24].

The other approach to artificial photosynthesis uses semiconductors, which transmit electrons, but do not absorb visible light. Yet by attaching a colored molecule, like manganese, to a semiconductor, such as titanium dioxide, sunlight can be used to move electrons, generating electricity. Further, this method can electrolyze or split water, which could provide a renewable source of hydrogen gas. The hydrogen gas can be used directly in fuel cells or converted into a more easily transported fuel, such as methanol [25]. Clearly, there is great potential in these research areas, but a large investment of time and money is necessary before artificial photosynthesis is a large-scale reality.

Strategies

Albert Einstein said, "the only source of knowledge is experience". In order for my students to be successful with the concepts in this unit, I designed several activities to facilitate each student's learning. The activities in this unit are hands-on and written to improve student's understanding of photosynthesis, a topic that is often over simplified or ignored in the standard Biology curriculum. The unit facilitates the teamwork and leadership skills of my students. They will work in groups to synthesize information and make presentations to their peers and the staff.

The unit will give students a depth of knowledge about renewable energy, specifically biomass. Students need to understand the problems associated with record high levels of carbon dioxide in the atmosphere. They need to research the renewable energy sources that could help us reduce our dependence on fossil fuels and reduce our carbon emissions. They need to learn to be skeptical because there are no easy solutions. Our students will inherit these problems, and we as teachers need to arm them with all of our knowledge. Even if students don't become scientists, they need to be science literate. They need to be able to understand current and upcoming technology, ask good questions, and not allow our government or companies to continue to delay a solution.

I will teach my unit over a 4-week period, just following a unit on atmosphere and global warming. My unit will begin with an overview of the renewable energy sources and their potential to replace the fossil-fuel economy. We will focus primarily on the biological aspects of solar energy. Students will study photosynthesis to understand how light energy is converted into chemical energy and stored in organic molecules like glucose. We know glucose as fuel for our bodies, but the chemical bonds in plants can also become fuel for our cars and homes as well. Learning activities for photosynthesis will include an activity in which students portray the atoms in part of the photosynthesis reaction. They will move and recombine just as atoms of oxygen and hydrogen move and recombine when light energy is harnessed by plants. Students will also participate in demonstrations with aquatic plants, for example Elodea, which generate oxygen bubbles in a water and sodium bicarbonate solution.

After learning about photosynthesis, students will study the carbon cycle, emphasizing the processes by which carbon dioxide is released into the atmosphere as well as how it is taken up out of the atmosphere. Students will quantify and compare the total amount of carbon stored in a tree (using the age, height and diameter) to the total amount of carbon dioxide that is emitted from a car. This activity allows students to compare the contribution of carbon dioxide from cars to the uptake of carbon dioxide from the atmosphere by plants. This comparison allows them to grossly estimate the number of trees needed per car to help offset their carbon dioxide emissions.

If trees and plants are full of energy-rich carbon compounds, how can we extract that energy into a usable form for transportation? Students will study ethanol and biodiesel, two fuels produced primarily from corn and soybeans that have gained attention in our push to reduce our use of fossil fuels. Students will research the production of ethanol and biodiesel and compare their costs and benefits, including unforeseen social and economic impacts on farmers and the food supply. We will make biodiesel from used vegetable oil in the classroom to demonstrate we can make valuable products from "garbage." Students will also see how simple the process is, and they will test the fuel's combustion in an oil lamp.

Throughout the unit, students will come to understand that no one energy source can replace fossil fuels with today's technology. In fact, a combination of these energies is needed to replace our dependence on fossil fuels. Further, energy conservation can immediately reduce our use of fossil fuels and our emission of GHGs. Students will analyze their own carbon dioxide contribution and propose ways to reduce their impact on the environment in their household. Finally, students will do an energy audit on our school, and present their findings and suggestions for energy and money savings to the staff. In order to implement their suggestions, the students will create advertising to be displayed throughout the school. Success of their campaign will be tracked by comparing energy bills before and after energy-savings strategies were implemented.

Class Activities

Activity #1 — Photosynthesis Role Play

Students have learned the equation for photosynthesis since the fifth grade, but students often don't understand that the process is a multistep reaction that takes place in different locations in the chloroplast. Students will learn the two-step equation by having each student portray an electron or an atom of hydrogen, carbon or oxygen.

Equation 1, Water Oxidation: $2\ H_2O + \text{light} \longrightarrow O_2 + 4\ H^+ + 4\ e^-$

Equation 2, Carbon Dioxide Reduction: $6\ CO_2 + 24\ H^+ + 24\ e^- \longrightarrow C_6H_{12}O_6 + 6\ H_2O$

The first step of this activity is to teach students about oxidation and reduction. One student volunteer will portray a hydrogen atom with 1 valence electron. Students will be given a necklace of Velcro that represents the outer shell of valence electrons. I will demonstrate oxidation by removing the one valence electron from hydrogen. I will demonstrate reduction by giving the electron back to the hydrogen atom. These are crucial concepts to understand for further study of photosynthesis. Next, student volunteers will form two water molecules (4 H students, 2 O students, and crepe paper for bonds) and demonstrate water oxidation. One student will portray the Sun, by breaking the bonds and the students will reassemble into an oxygen molecule and four hydrogen ions, each with an electron removed. The fate of the four electrons liberated by the splitting of water will be the transition into our investigation of the electron-transport chain and the Calvin

Cycle.

Activity #2 - Carbon Neutral Cars?

It is now hip to be carbon neutral. Going carbon neutral means that you do not add to the amount of carbon dioxide that is currently in the atmosphere. This is not a easy thing to do. An average house can add over 39,000 pounds of carbon dioxide to the atmosphere each year, and driving a car 10,000 miles produces 8,000 pounds of carbon dioxide. Going carbon neutral involves using renewable energy sources that don't add to atmospheric carbon dioxide levels. This is not always possible, though, if you travel by airplane. New companies have sprung up to sell carbon offsets, which go toward reducing carbon dioxide emissions elsewhere. For example, Terrapass is a company that sells offsets and uses the money to invest in windfarms or biofuel projects [26].

This goal of this activity is for students to determine how many trees are necessary to offset the amount of carbon dioxide given off by various cars. They will determine the amount of carbon stored in a tree to give an approximation of the total amount of carbon dioxide taken up by the tree during photosynthesis. Then, students will calculate the amount of carbon dioxide emissions from various cars. They will compare the values and determine how many trees are needed to offset the car emissions each year.

First, students will measure the height and calculate the area and volume of the tree. An easy way to measure tree height utilizes geometry and trigonometry concepts. A clinometer can be made simply using a clinometer sheet, a straw, weight, and a table of tangents. The clinometers sheet and table of tangents can be found at http://www.globe.gov/tctg/tgchapter.jsp?sectionId=201. A measuring tape can be used to measure the circumference of the tree, normally taken at breast height, or 1.5 m from the base of the tree. The formulas for calculating area and volume are given below.

Step 1 — Measure tree height and calculate tree volume

Tree Height ______ meters

Circumference of tree at chest height (at approx. 1.5 m) ______ meters

Area of tree trunk = (Circumference ^{2})/4Π ______ meters ^{2}

Total Volume of tree trunk (Area * Height) ______ meters ^{3}

Step 2 — Estimate the mass of carbon in the tree.

To calculate the amount of carbon in kg, we need to use the density (D) of wood and volume (V) of the tree.

Sample Tree Densities

White Oak: 0.68 g/cm ^{3} Scotch Pine: 0.53 g/cm ^{3}

Douglas Fir: 0.48 g/cm ^{3} America Beech: 0.64 g/cm ^{3}

Mass (M) of tree trunk (D = M/V) ______ Total kilograms

40% of the dry weight of a tree is carbon. ______ Kilograms of C

Using this information, how much of the tree is carbon?

Step 3 — Estimate the amount of carbon dioxide emissions.

To calculate the amount of carbon dioxide, we will assume that the car is driven 12,000 miles per year (this is a low estimate).

Calculate the number of gallons of gasoline used per year for the following 4 cars/trucks and their average miles per gallon.

Hybrid — approx 50 miles/gallon Hummer — approx 12 miles/gallon

Pick-up — approx 16 miles/ gallon Mid-size sedan — approx 24 miles/ gallon

Convert the gallons per year to liters per year. 1 Gallon = 3.785 Liters

Calculate the amount of grams of Carbon emitted by the following equation:

(________ L gasoline consumed/yr) * (49.3 g C/L gasoline) = ________g Carbon/yr

Convert the result to kilograms (divide by 1000) and compare to the amount sequestered by your tree.

How many trees would each of the cars require to sequester the amount of carbon produced?

Activity #3 — Energy Action Plans for Home and School

Students will use the internet to calculate the amount of carbon dioxide that their household produces (every year or month). They may use multiple websites to calculate this amount as some variation will occur. Here are some sites that give a good carbon estimation:

- http://www.epa.gov/climatechange/emissions/ind_calculator.html
- http://www.climatecrisis.net/takeaction/carboncalculator/
- http://www.safeclimate.net/calculator/

The students should then do research about the changes that they can implement in their house and what the costs or saving for each change would be. The student's research will be compiled into a report that they will present to their families. The students should keep track of the changes in their household's carbon dioxide emissions over the course of the semester and report changes, challenges and successes.

The students will then research the amount of energy used and money spent by their school building. They will propose ways that money could be saved, and then the students will present their multi-step plan for energy and money saving to the faculty and staff. If approved, the energy-saving strategies will be presented to the entire school and advertised through signs and posters. The students will track their energy savings over the course of the school year. The results of this project will be submitted to the school board and superintendant as a model for how students can develop and carry out a plan of action which provides a savings to the school district and empowerment to the students that they are part of the solution to the environmental problems which our students will inherit.

Resources

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Additional Teacher Resources

Carbon Cartoons http://www.npr.org/templates/story/story.php?storyId=11662978&ps=bb6

Curriculum Resources. David Walker.

http://www-saps.plantsci.cam.ac.uk/pub_support.htm

Ethanol Curriculum: Northwest Iowa Community College

http://www.nwicc.com/pages/continuing/business/ethanol/Module1.htm

National Renewable Energy Laboratory http://www.nrel.gov/

Energy Activities for Teachers And Students. Energy Information Administration.
http://www.eia.doe.gov/kids/classactivities/teachers&students.html

Student Readings/Resources

A New Leaf in Time: http://www-saps.plantsci.cam.ac.uk/articles/broad_anlit.htm

NPR Carbon Cartoons: http://www.npr.org/templates/story/story.php?storyId=11662978&ps=bb6

Energy Kid's Page. Energy Information Administration. http://www.eia.doe.gov/kids/energyfacts/index.html

Class Resources

Computers with internet access

LCD Projector/Overhead Projector

Art Supplies: Poster board, Markers, etc.

Fabric and Velcro to make valence shell and electrons

Appendix

Implementing District Standards

BIO.1 The student will plan and conduct investigations in which

b. hypotheses are formulated based on direct observations and information from scientific literature;
c. variables are defined and investigations are designed to test hypotheses;
d. graphing and arithmetic calculations are used as tools in data analysis;
e. conclusions are formed based on recorded quantitative and qualitative data;
f. sources of error inherent in experimental design are identified and discussed;
g. validity of data is determined;
h. chemicals and equipment are used in a safe manner;
i. appropriate technology including computers, graphing calculators, and probeware, is used for gathering and analyzing data and communicating results;
j. research utilizes scientific literature;
k. alternative scientific explanations and models are recognized and analyzed; and
l. a scientific viewpoint is constructed and defended (the nature of science).

BIO.3 The student will investigate and understand the chemical and biochemical principles essential for life. Key concepts include

b. the structure and function of macromolecules;
c. the nature of enzymes; and
d. the capture, storage, transformation, and flow of energy through the processes of photosynthesis and respiration.

BIO.9 The student will investigate and understand dynamic equilibria within populations, communities, and ecosystems. Key concepts include

b. nutrient cycling with energy flow through ecosystems;
d. the effects of natural events and human activities on ecosystems; and

Implementing National Standards (9-12)

CONTENT STANDARD A: All Students should develop the abilities necessary to do scientific inquiry.

1 Use technology and mathematics to improve investigations and communications.

CONTENT STANDARD B: As a result of their activities in grades 9-12, all students should develop an understanding of

- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Conservation of energy and increase in disorder
- Interactions of energy and matter

CONTENT STANDARD C: All students should develop understanding of

- Matter, energy, and organization in living systems

CONTENT STANDARD D: All students should develop an understanding of

- Energy in the earth system
- Geochemical cycles

CONTENT STANDARD E: All students should develop

- Abilities of technological design
- Understandings about science and technology

CONTENT STANDARD F: As a result of activities in grades 9-12, all students should develop understanding of

- Personal and community health
- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges