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Solar VS Fossil Fuel Generated Electricity: Can Physics Determine Which is Best For You and Your School?

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by Brian Barrientez

Introduction

The William C. Overfelt High School community is located in the Eastern section of California's third largest city; San Jose, with an ethnic makeup of predominately Mexican American with smaller percentages of African American, Samoan, Filipino, Cambodian, and Vietnamese. The area is also one which was hardest hit during the collapse of the real estate market with hundreds of homes being foreclosed each year adding to the already existing high rate of poverty. The student population of Overfelt High School is 75% of Hispanic ethnicity, 9% Asian, 7% Filipino, 2% African American, and less than 1% White with slightly over 35% of the student population designated LEP (Limited English Proficient). Student enrollment over the last twenty one years has dropped from a high of 2,238 in 1990 to 1520 during the 2010-2011 academic year. [1]

The single largest contributing factor for the declining enrollment has been the transfer of students from Overfelt High School to other schools within the district, charter schools or schools with Magnet programs as a result of Program Improvement under the No Child Left Behind mandates. Predominantly all of the transferring students have been those at the higher end of the academic achievement level contributing to Overfelt becoming the lowest achieving high school in Santa Clara County as identified through API scores. The transfer of higher achieving students out of Overfelt High School has resulted in a large percentage of students who are not academically prepared to take Physics and a second sub-group of students who may be academically prepared but choose not to take Physics due to the challenges of the course and the absence of understanding the importance of academic achievement, both personally and at home. For these reasons my Physics curriculum must be academically challenging, interesting, have multiple pathways for student success, and meet the diverse learning needs of the academically advanced and lower achieving students within my classroom. In designing my curricular unit I had to focus on my students' abilities, culture, and the new content standards for science. Of equal consideration is the fact that according to the 2010-2011 API report [2] , the educational statistics relating to the parents of my students indicate that: 67% of parents did not graduate from high school, 21% graduated high school, 7% had some college experience, 5% are college graduates, and 1% had a graduate degree. Thus, in order to truly raise environmental awareness and responsibility, my curriculum must involve educating my student's parents and families also.

Rationale

Sometimes I think when my students were born one of the first procedures that the doctor performed was to plug the student into the nearest electrical outlet and check to ensure that their entire "tech" was working properly. After all, my students, like so many other "typical" high school students across America, have the same daily behaviors and routines which begin immediately upon waking up. Sleepy eyes slightly open, they first fumble for their "tech." They switch on a radio or TV and then mentally run through their personal "check list" for the day which usually includes removing an IPod® or IPhone® or some similar device from the wall charger (while leaving the charger still plugged into the wall wasting electricity) or for many students, this may also include a small, hand held gaming device such as a PSP®, IPad® or laptop. Regardless of what "tech" item the student prepares for their day, the one commonality is that all of these items require electricity. My students believe that electricity is there for the taking, an unlimited supply freely flowing through the outlets. Just plug in and power up. The sky is the limit and there is never a cloudy day. A thought is never given to the cost of the electricity, how it is generated, or transmitted. The students don't have a clue as to the enormous amount of pollution generated from the conversion of our dwindling fossil fuel resources into electricity and the health problems associated with that conversion. Compounding this problem is the great disconnect between my students lack of knowledge concerning electricity and all of the phenomenal, environmental, "green, "accomplishments of the City of San Jose, the City which they call home.

San Jose is the tenth largest City in the United States with a population exceeding one million. According to the United States Census Bureau, San Jose's population has been steadily increasing over the last three decades. Coinciding with this increase in population has been the increase in energy use, specifically electricity. Over the last thirty years, the average household and personal demand for electricity has greatly increased. In the past, most homes had one, maybe, two televisions and a single telephone. Not like the plethora of electrical devices today which adorn the modern household and are found on individual students. My personal concern, as their high school Physics teacher is, "how do I get my Physics students to begin to understand their individual and household energy use along with the adverse environmental effects of such use?" How do I accomplish these objectives while meeting all other academic obligations of incorporating the new Common Core Standards for Physics, improving their reading, writing, (literacy), and critical thinking skills, while at the same time prepare the students so that they can successfully pass the California Science Test for Physics? The answer to accomplishing all of these objectives while providing the students with an exceptional educational experience which involves their families was the development of this curricular unit. The first step in formulating this unit was choosing my seminar. I chose the seminar, "Energy, Environment, and Health" by Dr. John Wargo of Yale University because the topics presented and to be discussed were exactly what I needed for my unit.

Dr. Wargo's seminar, through the Yale Teachers Initiative, helped me to understand the concept that every technological advancement has a consequence. Many times the consequence is not easily identified and may lay hidden in the environment due to the complex relationships between human interactions with the environment. As an example, which we discussed in class, most people now spend over 90% of their time indoors and most modern buildings are heavily insulated to conserve energy. Although this may seem very beneficial to the environment, in a green sense, what if the air inside the building were to slowly become contaminated from vapors released from the multitude of chemicals used in insulation manufacture? Compounding this possible problem could be a limited fresh air supply due to the recirculation of air in the building, once again, done as a means to conserve energy. Dr. Wargo helped me understand the complex relationship which exits between our natural environment and our "built" environment. I would like this curricular unit to help my students understand these complex relationships in terms of renewable and non-renewable resources; specifically, oil, natural gas, and solar energy. At the end of this unit I will be posing a series of questions to my students in the form of "problem based learning," and they will be required to make informed decisions as to the "costs" of using renewable energy as opposed to non-renewable energy and the associated health concerns resulting from their decisions.

Background

Non-Renewable Energy: Fossil Fuel Reserves

Currently the United States is dependent on fossil fuels as its main source of energy. The United States currently imports almost half of the oil consumed by the United States and a small percentage of natural gas which makes us increasingly dependent on foreign sources of fossil fuels and increasingly involved in the economic and political structures of the source country. In terms of energy use, seventy percent of the nation's electricity is generated through the burning of coal and natural gas, sources which are non-renewable. Non-renewable means that once the supply is depleted then it cannot be replaced, the glass is empty. In 2009 British Petroleum estimated worldwide fossil fuel reserves will supply, at current consumption, 205.0 thousand million tonnes of oil to last 46 more years, 6621.2 trillion cubic feet of natural gas to last 59 years, and finally 826,001 million tonnes of coal to last 118 years. Keep in mind that these estimates are based on current consumption. Every year as our world population increases so does our need for energy. This increase in population and energy consumption differ in that the world consumption of energy is increasing at a much faster pace than the population increase. This difference between the two indicates that the estimated fossil fuel reserves will not last as long as predicted. It is easily seen from this information that we are at a cross roads, we are running out of energy in the conventional sense from the utilization of fossil fuels. We have a few choices and we must convey the importance of these choices to our students. Although this section is for providing background information, I want to take a moment to diverge and underscore the importance of energy conservation. As opposed to waiting for the preplanned time in our science unit when we discuss energy or when the implementation of this curricular unit is appropriate in your teaching plans, I would suggest the following. Instead of beginning your energy unit by knocking your students over with a giant mallet and proclaiming that from this day forward they will now be budding environmentalists, you may prefer a more subtle, long lasting approach, a student friendly approach which involves student choices.

One simple choice which can be easily accomplished by every member of our society, especially our students, is to decrease our consumption of fossil fuels. As a teacher you can model this without ever having to explain what you are doing. As an example, as you go about your daily routines of teaching take a moment to evaluate how you personally can reduce your energy needs in your classroom environment. There are so many simple tasks which you can perform such as: turning off lights in empty rooms, controlling the thermostat in the classroom, if you have windows, use them and reduce the amount of artificial lighting in the room, and better monitoring and controlling of the amount of waste and recycling in the classroom. As the year progresses you will notice that these simple tasks become lifelong behaviors and you will be more energy efficient. And when you eventually begin this curricular unit or any unit involving energy, you will have a perfect springboard into the unit by having the students critique your energy usage in the classroom. If you can teach these concepts to your students through modeling, there is a better chance that they too will model these positive behaviors and begin them at home. If these simple energy reduction behaviors become the norm with the students' families, then I believe we can easily reduce our energy needs in as little as a semester and thus conserve energy and more importantly, begin to get students to evaluate their personal energy needs.

As opposed to reducing our use of energy, a second choice in meeting our increasing demand for energy would be to identify more reserves of coal, oil, and natural gas. We have identified and located all of the easily found, large reserves of natural gas, oil, and coal around the world, but what about the smaller reserves? Exploration and eventual extraction of these smaller reserves will be extremely cost intensive for companies. Coal mining may continue as humans and machines begin to mine at greater depths which greatly increase the costs and potential for loss of human life. Exploration at greater ocean depths, off shore, means greater water pressure and ocean current flow which produce their own unique set of problems. Drilling at greater depths on land requires equipment which can endure greater pressure and temperatures or require the use of the controversial method of natural gas and oil extraction known as "fracking."

Fossil Fuel Hazards

Fracking involves drilling into natural gas or oil reserves and injecting a highly pressurized fluid mixed with sand into the reservoir rock. Drilling may be straight down into the ground, or at any angle below ground, and drilling can be done horizontally along rock layers. With the increasing pressure in the bore hole, hydraulic induced fractures occur which allow oil or natural gas reserves to migrate through these "cracks" and then be extracted. All in all, the search for and extraction of smaller fossil fuel reserves will be extremely expensive compared to current fossil fuel prices. But it is expected that the ever increasing demand for fossil fuel generated energy combined with the dwindling reserves will make the extraction of fossil fuel from these smaller reserves very profitable. Two other extremely important concerns for continued fossil fuel dependency involve the political and environmental realms. As a search intensifies to locate the smaller reserves of natural gas, oil, and coal, companies may have to negotiate lucrative "mineral right" contracts with the countries who sit atop these fossil fuel reserves. This may prove to have a positive impact on countries that could really use the money to improve the standard of living in the country or, it could have the opposite effect in countries ruled by leaders who could use the increase in wealth to further their regimes. Not only are the problems associated with fossil fuels worldwide and national, but they cause a multitude of problems in California as well.

California electricity is derived from a variety of sources as depicted in Figure 1 for the 2007 year. Depending on the source, whether the electricity was generated from the burning of fossil fuels or from a renewable source, or combination of both, the average price per kilowatt hour of electricity in California was almost 15 cents for the month of March, 2012. [3] Although this may seem like a bargain to some, especially if you purchase electricity at this low price, it truly is not a bargain because of what is not included in the cost. The average consumer has little idea of the extent of environmental damaged created from the burning of fossil fuels; especially oil and coal. One of the far reaching, damaging byproducts from burning of fossil fuels is referred to as, "greenhouse gasses."

According to the Environmental Protection Agency (EPA) in 2010 the United States produced greenhouse gasses (GHG) composed of the following gasses and average percentages: Carbon Dioxide (CO_2), 84%; Methane (CH_4), 10%; Nitrous Oxide (N_2O), 4%; and Fluorinated gasses, 2%, Figure 2. These gasses are referred to as greenhouse gases because they create the effect in the earth's atmosphere similar to the environment found in a greenhouse. Sunlight enters the earth's atmosphere and a portion is reflected back from the surface of the earth back up to the atmosphere as heat (infrared radiation). This reflected heat strikes the greenhouse gasses and much of it is absorbed or trapped and not allowed to leave the atmosphere, hence the slow warming of the earth's atmosphere which is changing our climate worldwide. The gasses are also responsible for air and water pollution, increasing acidity of the atmosphere, and the ever increasing, devastating effects to our health from particulate matter (PM), especially those classified as fine-particulate matter, released into the atmosphere from the burning of fossil fuels.

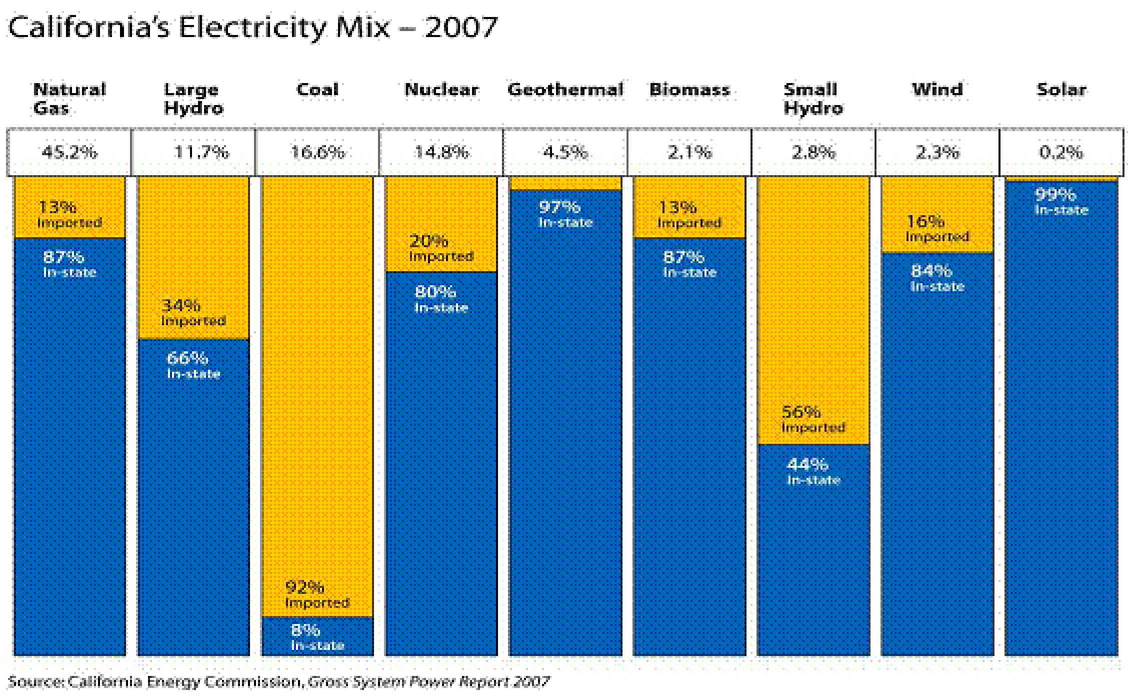

Figure 1 [4]

Gas Name	Chemical Formula	Percentage of GHG for 2010	Life time in atmosphere (years)
Carbon Dioxide	CO_2	84%	1
Methane	CH_4	10%	12
Nitrous Oxide	N_2O	4%	120
Fluorinated Gases including		2%	1 – 50,000

Figure 2 [5]

According to the EPA, coarse particulate matter is composed of particles with a diameter larger than 2.5 micrometers and less than 10 micrometers. The particles which have the greatest effect on human health are those particles which are labeled as "fine particulate matter" which have a diameter smaller than 2.5 micrometers. The reason that fine particulate particles are of great concern is the fact that they can be inhaled deep into the lungs where they may enter the bloodstream. Fine particulate matter is responsible for triggering heart attacks in people, especially fatal heart attacks in those who have a history of heart problems and cause an increase in difficulty breathing for those suffering from asthma. The very young and old are at the greatest risk from fine particulate matter and when cities have poor air quality days it is not uncommon for a dramatic increase in emergency room visits for respiratory related problems. But, coarse and fine particulate matter problems are just a few of the identified hazards associated with the burning of fossil fuels. Water and land pollution are of major concern especially as newer technologies such as fracking are implemented for the extraction of oil or natural gas from reserves which are not easily assessable by conventional recovery methods.

There are five major concerns associated with of the fracking process in terms of pollution and hazards. First is the concern over the huge quantities of water which are pumped out of ground water reservoirs to be used in the fracking process itself. The removal of these huge quantities of water may lower water tables and interfere with aquifers primarily used for drinking or agriculture. The second area of concern is possible pollution and contamination of surface areas from chemical spills or leaks during the mixing or injection of the chemical laden fluids to be pressure pumped underground. Thirdly, the injection and fracking process itself may pollute underground water aquifers. Fourth, contamination or spills from the recovery of the injected fluids used. The fifth concern deals with the treatment of the waste fluids from the entire process. Currently the EPA is in the process of collecting data related to these five major concerns and more information will be available through the EPA as data is collected and analyzed. Thus, even though the electricity in California was almost 15 cents per kilowatt hour in March, the actual cost is substantially higher from all of the environmental and health problems associated with burning fossil fuels. Please keep in mind that I believe we have not yet identified all possible health related issue arising from the burning of fossil fuels at this time. As we improve our technology and understanding of the human body, especially on the cellular level we may find a whole other host of possible problems. On a more positive note, the City of San Jose California is using newer technologies and is working diligently to make San Jose the most environmentally friendly city in the nation.

San Jose's Energy Consumption and Associated GHG Generation Electricity

In 2008 the City of San Jose consumed slightly over 5,400,000 Megawatts/hour (Mwh) of electricity with a resulting Carbon Dioxide pollution of over 1,570,000 Metric Tons of CO_2 ($MTCO_2$) as shown in Figure 3. One megawatt-hour of power is a large amount of power and as a means of putting this into perspective, consider the following scenario:

A large warehouse will be available for one of the largest book reading gatherings in the world. In anticipation of the arrival of the avid readers, 10,000 light bulbs rated at 100 watts each will be used to provide adequate lighting for the event. If all of the lights are left on for one hour, then 1,000,000 watt hours or 1 MWh or electricity will be consumed as calculated below.

10,000 light bulbs X 100 watts each X 1 hour of use = 1,000,000 watt hours

= 1,000 kilowatt hours = 1 megawatt hour.

In a similar fashion of relativity, consider the amount of volume contained in the 1,570,000 Metric Tons of CO_2 released into the atmosphere. It would occupy the equivalent volume of 833 Empire State Buildings.

Natural Gas

The consumption of natural gas was almost 6,400,000 thms with a resulting production of almost 2,800,000 Metric tons of CO_2 ($MTCO_2$) as shown in Figure 3. The Standard International unit of one therm (THM) may seem confusing but it is really not. Usually gases are measured or consumed in units of volume such as meters cubed or feet cubed but natural gas varies in its chemical composition. One cubic meter of gas from one location may contain substantially more impurities than an equivalent amount from another location.

Because of this difference in "heat energy" per volume the "therm" was introduced in the United States in 1968 to better be able to accurately measure the heat energy of gas and charge the customer or consumer accordingly. The City of San Jose became very concerned with its energy use and resulting "carbon footprint" (CO_2) and as a means to help reduce its dependency on fossil fuel generated electricity, improve the air quality and overall environment within the City, San Jose drafted, adopted, and passed one of the most comprehensive "Green" plans of any city in the country.

San Jose City's consumption of electricity and natural gas and associated production of CO_2 for 2008

	Kwh Electric Energy Consumed	GHG Produced ($MTCO_2$)	Natural Gas Consumed (THM)	Natural Gas Consumed (Kwh)	GHG Produced ($MTCO_2$)
San Jose	5,402,091,198	1,570,688	217,160,245	6,364,363,558	1,152,487

Figure 3 [6]

San Jose Power Plants

The City of San Jose receives most of its electricity from three major natural gas burning power plants. They are the Agnews Power Plant, Metcalf Energy Center, and Los Esteros Critical Energy Facility as shown in Figure 4. As of this writing, the Los Esteros Critical Energy Facility is undergoing remodeling in order to upgrade its' gas fired, simple-cycle system. The baseload values represent the constant or "baseload" supply of electricity which the power plant can generate continually under normal conditions. The "peaking" is the maximum amount of electricity the power plant can generate if needed during high demand situations. All three power plants burn natural gas, and like the burning of all fossil fuels for electricity generation, this process is very inefficient. Approximately one-third of the energy contained in the original unit of fossil fuel is converted to usable electricity provided to the end user. The huge loss of energy is found in the burning of the fossil fuel and the associated heat from that burning, the operation of the power plant itself, and the transmission of electricity through various sub-station and power stations prior to reaching the consumer.

After an extensive analysis of their energy consumption, greenhouse gas production, and a quickly increasing population, the City of San Jose decided to take action. They did not just go "green" but decided to be the leading city in the nation for green technology throughout the entire City.

San Jose, California Electricity Generating Power Plants

	Operation Date	Baseload (MW)	Peaking (MW)	Ownership	Technology	Turbines
Agnews Power Plant	April 1990	28	28	Calpine 100%	Natural gas fired-combined cycle cogeneration	GE combustion and Shin Nippon steam
Metcalf Energy Center	June 2005	564	605	Calpine 100%	Natural gas-fired, combined-cycle	Siemens Westinghouse gas and steam
Los Esteros Critical Energy Facility	March 2003 Offline for upgrades	243	309	Calpine 100%	Natural gas-fired, simple-cycle	GE combustion

Figure 4 [7]

San Jose's Green Vision Plan Overview

In October of 2007, the City of San Jose released its' "San Jose's Green Vision" document. This document was the result of countless hours of research in order to determine the best way for the entire City to become green with a City sponsored plan covering every aspect of San Jose from City Government to new construction, and utilization of renewable sources of electricity. San Jose has received many awards and honors for the adoption of this plan and is recognized as has having the most ambitious plan of any city in the nation in an attempt to be the most innovative, creative, and successful city in the country in implementing "green" standards. San Jose's 10 goals are listed below in Figure 5. My curricular unit falls right into alignment with goal number 3 and stresses the importance of using electricity generated from renewable sources such as solar.

Green Vision Goals
Within 15 years, the City of San José in tandem with its residents and businesses will:
1. Create 25,000 Clean Tech jobs as the World Center of Clean Tech Innovation
2. Reduce per capita energy use by 50 percent
3. Receive 100 percent of our electrical power from clean renewable sources
4. Build or retrofit 50 million square feet of green buildings
5. Divert 100 percent of the waste from our landfill and convert waste to energy
6. Recycle or beneficially reuse 100 percent of our wastewater (100 million gallons per day)
7. Adopt a General Plan with measurable standards for sustainable development
8. Ensure that 100 percent of public fleet vehicles run on alternative fuels
9. Plant 100,000 new trees and replace 100 percent of our streetlights with smart, zero emission lighting
10. Create 100 miles of interconnected trails

Figure 5 [8]

Photovoltaic Cell Design, Function, and Efficiency

The French Physicists, A. E. Bacquerel is credited as being the person responsible for building the first photovoltaic cell in 1839 at the age of 19. In 1905 Albert Einstein explained the "physics" behind the photovoltaic effect and received a Nobel Prize for his efforts. Over the years, many others continued working on the advancement of photovoltaic cells (PV) in an attempt to bring the cost of renewable electricity produced from a (PV) equivalent to the costs from obtaining electricity from fossil fuel. Consider that in 1955 Bell Laboratories perfected a photovoltaic cell which was 6% efficient. Bell Laboratories' cell produced one watt of electricity for $250 and electricity generated from the burning of coal cost a little over $3 for a watt at that time. Instead of just letting the entire photovoltaic cell sit as an interesting phenomenon, Bell Laboratories pushed forward to improve the efficiency and lower the costs of electricity produced by photovoltaic cells due to the promising use of the cells on satellites. Modern photovoltaic cells are much more efficient and are getting better, literally every day, as more and more financial resources are directed toward improving photovoltaic cell efficiency and lowering production costs. The average conversion of solar energy into usable electricity is approximately 18%, but new photovoltaic cell prototypes are averaging almost 40% efficiency which will greatly increase the amount of electricity produced by the cells. Most "basic" photovoltaic cells are made from silicon.

Silicon was one the earliest elements used for making photovoltaic cells and is still the most commonly used material today. Pure silicon is element number fourteen on the Periodic Table, consists of 14 protons and electrons, and is the second most abundant element on the earth. It has three energy levels with four valance electrons in the last energy level. In pure silicon, the outer four electrons of silicon share a bond with the outer four electrons of another silicon atom. In order to make pure silicon a "semi-conductor," small amounts of other elements are exchanged for silicon atoms in the silicon crystal structure in a process called, "doping." In a very simplified overview of how a photovoltaic cell is constructed, the cell begins as two extremely thin semiconductor plates sandwiched together. Both plates are made of silicon and together, both are electrically neutral, with one side positive and the opposite side negative.

Atoms of phosphorus, element 15 on the Periodic Table, have 15 electrons and 15 protons respectively. Some atoms of phosphorus are added to the crystal silicon structure and take the place of silicon atoms. Since phosphorus has 5 valance electrons, four of the electrons bond with four silicon valence electrons leaving an extra electron. As more and more phosphorus atoms are exchanged for silicon atoms, an abundance of "free" electrons form. The "extra" electrons are available for bonding and this structure is now referred to as a negative plate or n-type plate with an electric field due to the "free" electrons. The positive layer of the photovoltaic cell is created in much the same manner.

Boron, element 5 on the Periodic Table, has 3 valance electrons and like phosphorus is exchanged for a silicon atom in the silicon crystal structure. When the boron atom is exchanged for the silicon atom in the structure, there are only 3 electrons available for bonding instead of four. This situation creates a "hole" because the missing electron leaves one "extra" proton in the structure. This layer is now called the positive plate or p-type layer. Because both plates are electrically neutral together, energy (extra electrons) must be added into the system in order to get electrons to flow (electricity) out of the n-plate and fill the "holes" in the p-plate. When placed in sunlight, photons which compose sun light, strike the photovoltaic cell and their energy can dislodge an electron from the n-plate to fill a "hole" in the p-plate, beginning a flow of electrons. Since silicon wafers are extremely reflective and somewhat fragile, a glass sheet or a cover plate or some other type of protective material is placed over the cell to reduce its reflective nature and protect the photovoltaic cell. Please keep in mind that this is a very simplified example of the composition and function of a photovoltaic cell and much more detailed information is easily accessible on the web or check in the Teacher Resource section of this unit. Single photovoltaic cells can be assembled together to form "modules" and modules can be assembled together to form "arrays." On a larger scale, the arrays can then be configured to meet almost any electrical need by connecting them in "series" or "parallel."

Solar Panels: Series and Parallel

A solar panel (module) is an assemblage of individual photovoltaic cells usually encased in glass and housed in a metal frame. You can easily construct a working solar panel by assembling individual photovoltaic cells purchased from a source such as Ebay® to meet most common DC electrical needs or convert the DC electricity into AC through the use of a converter. Suppose, as an example, you purchase 24 cells and when placed in direct sunlight, a single cell can provide 0.5 V at 3.6 A. To assemble these cells into a solar module (panel) you would begin by laying out the cells six in a column by four columns. By connecting all six cells in a column together in series you would have a column with an output of 3 V and 3.6 A because in series, voltage adds and current remains constant as outlined below using the power equation.

In a series circuit, when adding voltage the current will remain the same. Thus, for the six cells in series you have:

(0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) = 3.0 V at 3.6A

The Power for this column of six cells would be

Power (W) = Current (A) X Voltage (V)

Six cells in series: Power (W) = (3.6 A) X (0.5 V X 6 cells) = 10.8 W

By continuing this process for all four columns you will now have four columns, each at 3.0 V and 3.6 A. The solar panel can then be brought to the "customary" 12 volts DC, simply by connecting these four columns together in series resulting in a 12 V module able to supply 3.6 A of current and a power output of 43.2 watts as outlined below.

Column 1:(0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V)

= 3.0 V at 3.6A

Column 2:(0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V)

= 3.0 V at 3.6A

Column 3:(0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V)

= 3.0 V at 3.6A

Column 4:(0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V) + (0.5 V)

= 3.0 V at 3.6A

For the Module: Column 1 (3.0 V) + Column 2 (3.0 V) + Column 3 (3.0 V) +

Column 4 (3.0 V) = 12.0 V at 3.6 A

Power (W) = Current (A) X Voltage (V)

Four columns in series: Power (W) = (3.6 A) X (3.0 V X 4 columns) = 43.2 W

If you need more watts, simply add panels together in parallel and construct an "array." As an example place four of the solar modules together in parallel where the voltage remains the same and the current increases as outlined below.

Power (W) = Current (A) X Voltage (V)

Four solar panels in parallel: Power (W) = (3.6 A X 4 panels) X (12.0 V) = 172.8 W

As you can see, by constructing your own solar modules and arranging them in series, parallel, or any combination you can generate the amount of electricity you will require for almost any need. With the inclusion of an inverter you can convert the DC electricity into AC. In fact, many home users of renewable solar generated electricity have a battery system to store electricity when the solar modules are not generating electricity due to cloudy conditions or night time. The same photovoltaic module system can be connected to a "power conditioner" which converts the DC electricity into AC (alternating current). The electricity can be used directly by the "load" (household use) and any excess electricity not being used can be sold to the local utility company.

The last component of a successful solar powered project is in understanding solar insolation. Solar insolation is the amount of sunlight in your area, which helps you to place your modules or a system at the best possible angle to collect the most sunlight and be as efficient as possible. NASA and the National Renewable Energy Laboratory have many maps and data sets available on line which will provide you with a good overview of the available sunlight and estimated kwh/m ^{2} /day in your area. Keep in mind that these are average yearly totals and the summer will provide more sunlight while the winter will provide less. A final thought to consider in determining whether or not to switch to a renewable source such as photovoltaic cells is to consider that in California the average cost of a single kwh is approximately 15 cents which is comparable to the cost of a photovoltaic cell produced, single kwh. But, when you add in the financial incentives from California's renewable energy rebates, the photovoltaic cell generated, single kwh drops to as little as 8.9 cents over the 20 year lifetime of the system.

Objectives and Teaching Strategies

The main goal of my Curricular Unit is to use the concepts of voltage, current, resistance, and power as instructional tools to educate students concerning their "carbon footprint" and the cost, other than monetary, for their consumption of electricity generated from the burning of fossil fuels. My students will be challenged to offer solutions to problems, as in my central question, "Solar VS Fossil Fuel Generated Electricity: Can Physics Determine Which is Best For You and Your School?" and will need to consider all environmental and health costs involved in any project requiring electricity. They will continue to explore the concept that, although fossil fuel generated electricity may be cheaper in some instances, is that cost the true cost, especially considering the data concerning pollutants from fossil fuel burning. I would like my students to walk away with the "big picture," that we truly are a global environment and just because you release some particulate matter into the atmosphere in the United States doesn't guarantee that it will not impede or affect the growth of an organism half way around the world or ten years down the road.

I would also like my students to understand the concept that energy, especially the development of renewable energy (solar) along with energy consumption and usage reduction will be at the forefront of social, political, and industrial growth for decades to come. Not to mention the ever increasing employment opportunities associated with renewable energy sources. Students, especially Physics students, must understand the basic concepts of energy production, use, and monitoring so as to be better informed citizens in making the right decisions for improving and protecting today's environment for future generations. Energy consumption is a global problem which will need a global solution. A solution which must transcend borders, cultures, languages, political, and social ideologies and be equitable for all as we truly have become a global family.

My unit is broken down into three sub-units with my overarching teaching strategies for my curricular unit based on the GRR (Gradual Release of Responsibility) model of instruction developed by Douglas Fisher and Nancy Frey. [9] Essentially this model of instruction begins with me carrying the bulk of the cognitive load and slowly shifting that load to the students through a structured model so that in the end students are completely responsible for their own, individual learning. All of my lectures and labs will be designed using this model and at the end of the unit students will be able to offer solutions to complex problems based on their understanding and successful meeting of unit objectives, then applying this knowledge and skill set to new situations.

Sub-units will be modularized with pre and post assessments to ensure that students are successfully meeting objectives. Formative assessments such as: exit slips, warm up journals, graphic organizers, self and peer review of text, etc. will be extensively used to monitor student progress and adjust curricula as needed to ensure student success. Each unit will contain lectures which introduce students to the needed Physics concepts and theories along with "hands-on" lab investigations to strengthen and reinforce students understanding of core concepts.

Classroom Activities

The first sub-unit will consist of four labs and focus on how DC electricity is measured in terms of use (kwh) along with its flow through "basic" series and parallel circuits. During this part of the sub-unit students will have the opportunity to explore their personal and family use of non-renewable, fossil fuel generated electrical energy (electricity) and the resulting "carbon footprint" and other environmental hazards created through the generation of electricity from fossil fuels. Prior to the first lab for this sub-unit students will have had numerous lectures covering "electrostatics" and "electric fields" which includes: electrical forces, charge, Coulomb's Law, electric fields and lines, electric potential difference and energy, and finally the flow of charge and electric current. This unit's lecture material will cover electric resistance, Ohm's Law, AC and DC electricity and finally electric circuits both series and parallel.

The first four labs are "cook book" type labs because students are reinforcing lecture topic concepts and physics theories while learning how to use a multimeter to measure voltage, resistance, and current in a simple circuit. These first four labs are pivotal for student success in the entire curricular unit. I have designed a simple "Physics Experiment Board" which students will use for these labs. All of the equipment for these labs can be purchased from RadioShack® or a similar store such as Fry's Electronics®. The equipment consists of the following:

Physics Experiment Board, Single "D" Battery Holder, Dual "D" Battery Holder,

Two "D" Batteries, Assorted colored jumper leads, Digital Multimeter

I designed the "Physics Experiment Board" using a simple rectangular "grid style pc-board" available from RadioShack® and attaching three light bulbs and six resistors to the board using small, nuts, bolts, and washers. The "bulbs" are small, screw base type, 2.47 V light bulbs attached to the board with light bulb sockets and the resistors are attached to the board by small screws with the posts sticking up about a quarter inch above the board which makes it easy for students to connect test leads to the different resistors.

In Lab 1 students will focus on using their multimeters to measure current, voltage and resistance. They will have been exposed to these concepts in lecture and through problems presented using GRR have had the time to practice solving problems calculating current, voltage and resistance. Students will also begin to draw simple schematics of the electrical components they are using such as the battery, light bulb, and resister. An analysis and reflection part of the lab will require students to use their collected data to calculate any combination of voltage, current, or resistance and then use the multimeter to physically check to see if their calculated value was correct. Percent error will be determined or discussed. Ohm's Law will be used extensively for the calculations in these first four labs.

Ohms Law

R = V/I

Where:R = the resistance, measured in Ohms (Ω)

V = the voltage, measured in volts (V)

I = the current, measured in amperes (A)

In Lab 2 the students will be using the same equipment and physically constructing simple DC "series" circuit using the battery(s), light bulb(s), and resistor(s). Using the rules for simple DC circuits the students will calculate the voltage, resistance, and current at various locations in the circuit. They will then be required to use the multimeter to check their calculated values at specified locations in the circuits. Lab 3 will require the same equipment and students will follow the same procedures as in Lab 2 but this time will be designing, constructing, and testing "parallel" circuits. During lecture and lab investigations students will receive multiple formative assessments so that lesson plans can be adjusted to meet student learning needs. One formative assessment will require each student to write a quiz to assess lecture concepts and equations along with a performance assessment lab to assess whether a classmate understands the basics of calculating and measuring current, resistance, and voltage in a simple DC circuit.

Students will exchange their written and performance assessment quiz with a fellow student. Each student will complete the quiz, and offer suggestions for improving the assessment, and discuss the data collected through the assessments. I use this method of formative assessment because it allows the students to "pairshare" and help each other to truly understand the material. I will choose a couple of the quizzes or questions from many of the quizzes and construct a summative assessment for this first sub-unit. The reason for the use of formative assessments is due to the fact that this first series of four labs forms the bases for all other labs to follow. The fourth and final lab of this sub-unit will require the students to learn how to read and understand the data provided in their family's utility bill and then go online to a site such as PG & E® to calculate their "carbon footprint." This lab will also be supported by lectures which will cover carbon footprint, greenhouse gases, and the revolutionary approach the City of San Jose is taking in becoming the leading "green" city in the nation.

In the second sub-unit students will explore the possibility of replacing a percentage of their fossil fuel generated electricity with renewable, solar generated electricity. One project which will aid students in exploring this replacement involves the design and construction of a small solar powered cell phone charging station and once again, calculating the effect on their "carbon footprint," and benefits to the environment. Included in the second sub-unit of my curricular unit will involve a series of lectures on solar insolation, solar cell design, function, and use, along with supporting labs.

Labs 5 & 6 will be very similar to Labs 1 through 3 but instead of using batteries as the voltage source students will use photovoltaic cells. They will be working outside for this series of labs. As before, numerous formative assessments will be given and lesson plans adjusted based on student needs. The final lab (Lab 7) of this second sub-unit will require students to form into 4 to 5 member engineering teams. Each team will be required to research and design a "working" solar powered charging station which will be able to charge a cell phone or portable music player. Engineering teams will need to prepare a proposal for their charging station which will include a schematic and all needed parts including a cost analysis. A written explanation of how the charger will function and the function of each individual component in the charging station will also need to be included in the proposal. As before, prior to any construction, engineering teams will exchange plans and critique each other's design and written report. After completing the evaluations and adjusting proposals, each team will meet with me for my critique and evaluation of their proposal. After receiving my input the teams will then acquire their parts and begin to construct their working solar powered charging station.

The third and final sub unit will require the students to work in small, engineering teams to demonstrate that solar powered alternatives can be designed and implemented in many situations on the urban high school campus to decrease the schools' "carbon footprint," save money through the use of renewable, solar energy, and have a positive impact on the campus environment. This final sub-unit of my curricular unit will require students to utilize all of their gained knowledge and skills to "problem solve." Critical thinking skills and creativity will be required as this final part of the curricular unit will allow students the opportunity to solve an open ended problem and justify their answer. Students will be divided into groups of 4 or 5 and choose a name for their engineering team. They will be challenged with a problem on campus in which photovoltaic cells can be used or traditional fossil fuel sources for the generation of electricity. Engineering teams will need to evaluate each situation and propose a solution to their problem in the form of a proposal. The formal proposal will include a written report concerning the environmental impact of their choice of energy source, complete costs and parts lists for the project including a time-line for job completion, drawings, diagrams, and schematics as needed. Each engineering team will present their proposal along with a small working model to the entire class who will serve in the capacity of the client. Students may use any media source they wish to present their proposal as a means of "selling" their ideas. Three examples of the "real life" problems are provided below:

Example 1: From Overfelt's Gardening Club to the Physics Club;

Congratulations!

We, the William C. Overfelt's Garden Club have recently completed our "urban" flower garden featuring only California native plants and trees. Due to the popularity of the garden and the beautiful summer evenings we would like to have installed lighting along the garden path so that the community could walk the gardens after dark. Our Club would like the Newtonians (Overfelt's Physics Club) to provide us with an estimate as to the cost of installing and maintaining such a system. Please remember that the Garden Club is "environmentally friendly" and would prefer to use a renewable energy source such as "solar power" if cost effective. We have attached a sketch of the gardens for your convenience and would like to have a cost estimate and a small working model within two weeks from today's date.

Sincerely;

Veronica Aguirre

Garden Club President

Example 2: From Overfelt's Athletic Department to the Physics Club;

Dear Newtonians (Overfelt's Physics Club);

The Athletic Department is currently planning on constructing a new, "snack shack" to be located on the far west corner of the field. This snack shack will require interior and exterior lighting, and two electrical outlets inside the snack shack to operate a large crock pot, two-50 cup coffee makers, and a handheld radio charging station. Because this new snack shack will only be used during regular season football, softball and soccer games, we would like to explore alternative energy sources to power this facility.

Please develop an alternative or "green" energy plan for us to consider. We would also like a small, model if possible to better help us understand and evaluate your system to confirm that it will meets our needs and be cost effective in maintenance. We look forward to meeting with you in the next two weeks from today's date and are very excited about the prospect of including some type of "green" technology in our program.

Sincerely;

Mark Delgado

William C. Overfelt

Athletics Director

Example 3: From Overfelt's Administration to the Physics Club;

Dear Newtonians (Overfelt's Physics Club);

As you are aware we had a small fire in the custodial building in early May. The fire was localized to the area which housed our golf carts, used for supervision, and the charging transformers for each cart. By October all repairs will have been made to the building and replacement golf carts will be arriving as we lost four in the fire. I am contacting you because of a conversation I had with your Club Advisor, Mr. Barrientez. He spoke very highly of your club and suggested that I should solicit assistance from your club for ideas to the following problem.

The charging transformers for the golf carts will be located in the same building as before, but many times the carts are returned to the building very late and do not get completely charged or charged at all if the custodians are running late. During the day it is not uncommon for many of the carts to just sit in front of the Administration building for hours until needed. A few of the carts may be used all day and have the batteries almost completely drained, but do not fully charge when returned so late in the evening. Thus, my question to you is, "can you devise a charging system using solar generated electricity which can be mounted on top of the Administration building and charge the golf carts while they are not being used?" Thank you in advance for your assistance. If possible could you please have a design, cost quote, etc. available for presentation along with some type of small working model or prototype in the next few weeks?

Sincerely;

Melissa Cortez

Associate Principal

Facilities and Maintenance

Appendix

The new Common Core Standards for Science will use focus on real-world problems using science and engineering. The specific Common Core Standards which will be addressed or are related to my curricular unit are:

Earth and Space Science

Core Idea ESS3: Earth and Human Activity

ESS3.A: Natural Resources

ESS3.B: Natural Hazards

ESS3.C: Human Impacts on Earth Systems

ESS3.D: Global Climate Change

Core Idea PS3: Energy

PS3.A: Definitions of Energy

PS3.B: Conservation of Energy and Energy Transfer

PS3.C: Relationship Between Energy and Forces

PS3.D: Energy in Chemical Processes and Everyday Life

Disciplinary Core Ideas – Engineering, Technology, and Application of Science

Core Idea ETS1: Engineering Design

ETS1.A: Defining and Delimiting an Engineering Problem

ETS1.B: Developing Possible Solutions

ETS1.C: Optimizing the Design Solution

Core Idea ETS2: Links Among Engineering, Technology, Science, and Society

ETS2.A: Interdependence of Science, Engineering, and Technology

ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

My curricular unit also covers the following, current, California State Science Standards:

5.a. *Students know* how to predict the voltage or current in simple direct current (DC) electric circuits constructed from batteries, wires, resistors, and capacitors.

5.b. *Students know* how to solve problems involving Ohm's law.

Resources

Teacher Resources

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"Appendix K Greenhouse Gas Emissions." San Jose, California, Department of Planning, Building and Code Enforcement, Notice of Preparation of a Draft Environmental Impact Report For the__project title__, last modified July 23, 2012, http://www.sanjoseca.gov/planning/eir/ESJ2040_GP/Appendix%20K%20-%20Greenhouse%20Gas%20Emissions%20.pdf Data tables of greenhouse gas emissions in the City of San Jose.

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"Greenhouse Gas Emissions: Greenhouse Gases Overview | Climate Change | US EPA." US Environmental Protection Agency, last modified June 14, 2012, http://epa.gov/climatechange/ghgemissions/gases.html. Useful information concerning greenhouse gas emissions.

"How Small Solar Electric Systems Work | Your Home | Energy Savers." U.S. Department of Energy, last updated February 9, 2011, http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=10720. Basic information and diagrams on how solar systems work in homes.

"Measuring Solar Insolation | Images." Earth Observatory, last updated April 19, 2001, http://earthobservatory.nasa.gov/IOTD/view.php?id=1355. World map of average solar insolation values.

Roberts, Billy. *Photovoltaic Solar Resource of the United States*. Renewable Resource Data Center, National Renewable Energy Laboratory, U.S. Department of Energy, October 20, 2008. Image. http://www.nrel.gov/gis/images/map_pv_national_lo-res.jpg. U.S. solar insolation map.

"SEDS | State Energy Data System." U.S. Energy Information System (EIS). http://www.eia.gov/state/seds/ (accessed July 16, 2012). State energy statistics.

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"Strategic Energy Plan." City of San Jose, last modified March 23, 2009, http://www.sanjoseca.gov/planning/gp_update/meetings/10-19-09/reading_materials/Energy/StrategicEnergyPlan_DRAFT_3-23-09.pdf . San Jose California energy plan for the future of the city.

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Basic resource for understanding and designing systems to generate electricity from wind power.

WuÌ^rfel, Peter, and Uli WuÌ^rfel. *Physics of solar cells from basic principles to advanced concepts*. 2nd, updated and expanded ed. Weinheim: Wiley-VCH, 2009. College level resource providing an in-depth understanding photovoltaic cell designs with all the math you need.

Student Resources

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Classroom Materials

RadioShack® Grid-Style PC Board with 2200 Holes

14" (35.3cm) Insulated Test/Jumper Leads

2.47V Premium-grade Incandescent Flashlight Bulb (2-Pack)

E10 Lamp Base with Screw Terminals

3/8" length, small steel bolts, nuts, and washers

Assorted resistors

Two "D" RadioShack® "D" Battery Holder

Single "D" RadioShack® "D" Battery Holder

"D" batteries

RadioShack® 1W Solar Panel 6V, cheaper to purchase photovoltaic cells from Ebay®

Endnotes

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9. Fisher, Douglas, and Nancy Frey. "Better learning through structured teaching: a framework for the gradual release of responsibility."