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The Dye-Sensitized Solar Cell

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Rationale

Questions

Most educators have (at some point in their career), been challenged by a student wishing to know why a given concept is important to learn. The question, "Why do we have to learn this" (which may seem as an attempt to derail or delay the day's classwork) is, in my estimation, always appropriate and deserving of an honest and complete answer. The "Question" is particularly important as it challenges me to genuinely analyze why *I* think a given concept merits my student's attention and intellectual engagement. I take great care when answering this question (and all other queries that challenge authority and accepted dogma), because it is the tenor of my (our) responses that fosters the kind of inquisitive, informed, and critical intellects needed in a world that is in a state of continual flux. These habits of mind are especially important in the science classroom where new technologies and ongoing research alter (and in many instances supplant) accepted scientific theories and beliefs. They are equally salient in our discourse on environmental policy where increasing populations and expanding economies threaten the sustainability of our ecosystems.

Recent discoveries of untapped deposits of oil and natural gas, along with new technologies that allow for the (relatively profitable) extraction and processing of these deposits have changed the outlook for the long range availability of fossil fuels. The realization that we may not run out of these environmentally damaging fuels in our lifetime debunks existing theories on the end of the era of fossil fuels and reframes the global discourse on the relation between energy usage and environmental policy (Mann 2013). Although the world's major economies have recently undertaken policies that would limit greenhouse gas emissions, (European Commission 2015) many of these efforts were driven by the belief that conservation was needed because we would at some point deplete our fossil fuel reserves (Grätzel 2005). That is no longer our reality. We are now faced with a new set of questions

How do we meet our increasing energy requirements in ways that are economically viable and mindful of our responsibility to the environment?

The new reality makes it more difficult to propose responsible energy policies that prioritize our environment over economic growth. We are therefore at an even more dangerous point in our collective history because our ever-increasing global population and the growth of newly developing economies will likely double our energy needs in the next half-century. Our newly discovered reserves of (seemingly limitless) fossil fuel reserves lead one to ask:

Why should we curtail our use of fossil fuels and use less efficient, more expensive renewable energy sources when fossil fuels are readily and cheaply available?

These and (other questions) will frame the discussions in my chemistry class as we consider our responsibilities as stewards of the environment. They are important questions because climate change is real, and my students will need to understand the risks we face if we continue present energy policies. More importantly, they will need to determine their roles and responsibilities as members of the global community. The unit will be especially important as it will provide a forum in which I can begin a discussion of environmental responsibility in a class where these issues are not usually discussed.

I teach chemistry and environmental science at the Philadelphia High School for Girls. We are a special admission school with a population of approximately 1400 girls. Students admitted to the school must have a minimum GPA of 3.5, excellent behavior records, and have advanced or proficient scores in state standardized assessments. The school is relatively diverse with 68% African American, 15% Asian, 12% Latino, 4% White, with a small percentage of African, and Middle Eastern students. While most of the students have outstanding academic records, many have had little or no comprehensive science classes during their middle school years. This has occurred because many schools in our district (in response to the pressures of state mandated standardized assessments), have focused their efforts on mathematics / literacy skills at the expense of a rich science curriculum. As a result, few have been exposed to science as a way of making sense of the world in which they live or (more importantly) of using science to answer the difficult questions our society faces.

The Common Core Literacy Standards (Common Core Initiative 2009), encourages teachers to provide opportunities for students to analyze and evaluate social and cultural issues that impact their lives. Doing so in the science classroom helps students to use science to resolve difficult problems in the real world (Mochizuki and Bryan 2015).

Energy is addressed as a general concept throughout my chemistry curriculum; however, the environmental consequences of current energy policies are not adequately addressed. An exploration of existing and future energy sources would help expand the range of the classroom discourse on energy while providing a forum in which to discuss how new energy sources can solve society's energy needs in a sustainable manner. Although I teach energy and its transformations as part of the chemistry curriculum, I did not have a deep conceptual understanding of how light energy is converted to electrical energy. Learning more about these electrochemical processes has greatly expanded my knowledge of solar energy and (in particular) the chemistry of solar cells.

Students will be able to use the concept of electron transfer to analyze the chemical reactions plants use to transform radiant energy to chemical energy. They should be able to evaluate the chemistry of fossil fuels and evaluate the effect of their continued use on the environment. They will also be able to assemble and measure the efficiency of a dye-sensitized solar cell.

Background

Energy and the Environment

It is difficult to concisely describe the importance of energy in modern industrial societies. From the electricity that charges the many electronic devices in our homes, to the combustion energy that propels the dizzying number of vehicles that traverse our roads and skies, to the chemical energy that sustains our life processes, energy in its various forms, pervades every aspect of our existence. The quality of our lives and the prosperity of our societies are determined in large part by the conveniences that abundant energy provides. However, our dependence on fossil fuels as our principal source of energy has had a profound effect on the ecosystems and climates that support life on our planet.

Our climate is maintained through a variety of interacting natural systems that control temperature, rainfall, wind and ocean currents. Each of these systems is influenced by the heat energy provided by the sun and regulated by the atmosphere. When solar radiation reaches our planet, some of it is reflected by the atmosphere, some reflected by the earth, but most of the energy is absorbed by the earth's surface. As the earth cools much of this heat is reradiated into the atmosphere (as infrared energy) where greenhouse gases (carbon dioxide, methane, and water) absorb and trap it in the atmosphere. This "natural greenhouse effect" is important as it helps maintain the earth's temperature in a range that supports the diversity of life on the planet. The excessive combustion of fossil fuels (the hydrocarbons: coal, petroleum, and natural gas), however, produces massive amounts of additional carbon dioxide that alters this delicate balance and contributes to increasing global temperatures. The principal reactions are as follows:

$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$ (Combustion of Coal)

$CH_4\ (g) + 2O_2\ (g) \rightarrow CO_2\ (g) + 2H_2O\ (g)$ (Combustion of Natural Gas)

$2C_8H_{18}\ (l) + 25O_2\ (g) \rightarrow 16CO_2\ (g) + 18H_2O\ (g)$ (Combustion of Gasoline)

Data collected since 1860 (mid industrial revolution) graphically illustrate the relationship between increased CO_2 emissions and global temperatures. The data show that CO_2 emissions have increased from 280 ppmv (parts per million by volume) in 1860 to over 400 ppmv in 2013 (a 40 % increase) **(EPA 2015)**). This trend is unfortunately likely to continue as the world's exploding population and newly developing economies will require even greater amounts of energy: the world demand (in 2007) of 13 TW is expected to grow to 20 TW by the year 2050 and 46 TW by the end of the century (Lewis 2007). Continued reliance on fossil fuels will increase pollution and greenhouse gas emissions, which will cause irreparable harm to our climate (Solomon, et al. 2009). It is clear that a shift towards renewable carbon neutral energy sources is the only way to meet our growing energy demands in a sustainable manner (Lewis and Crabtree 2005)

The supply and demand of energy determines the course of global development in every sphere of human activity. Sufficient supplies of ***clean***energy are intimately linked with global stability, economic prosperity and quality of life. Finding energy sources to satisfy the world's growing demand is one of society's foremost challenges in the next half century. (Lewis and Crabtree 2005, 3).

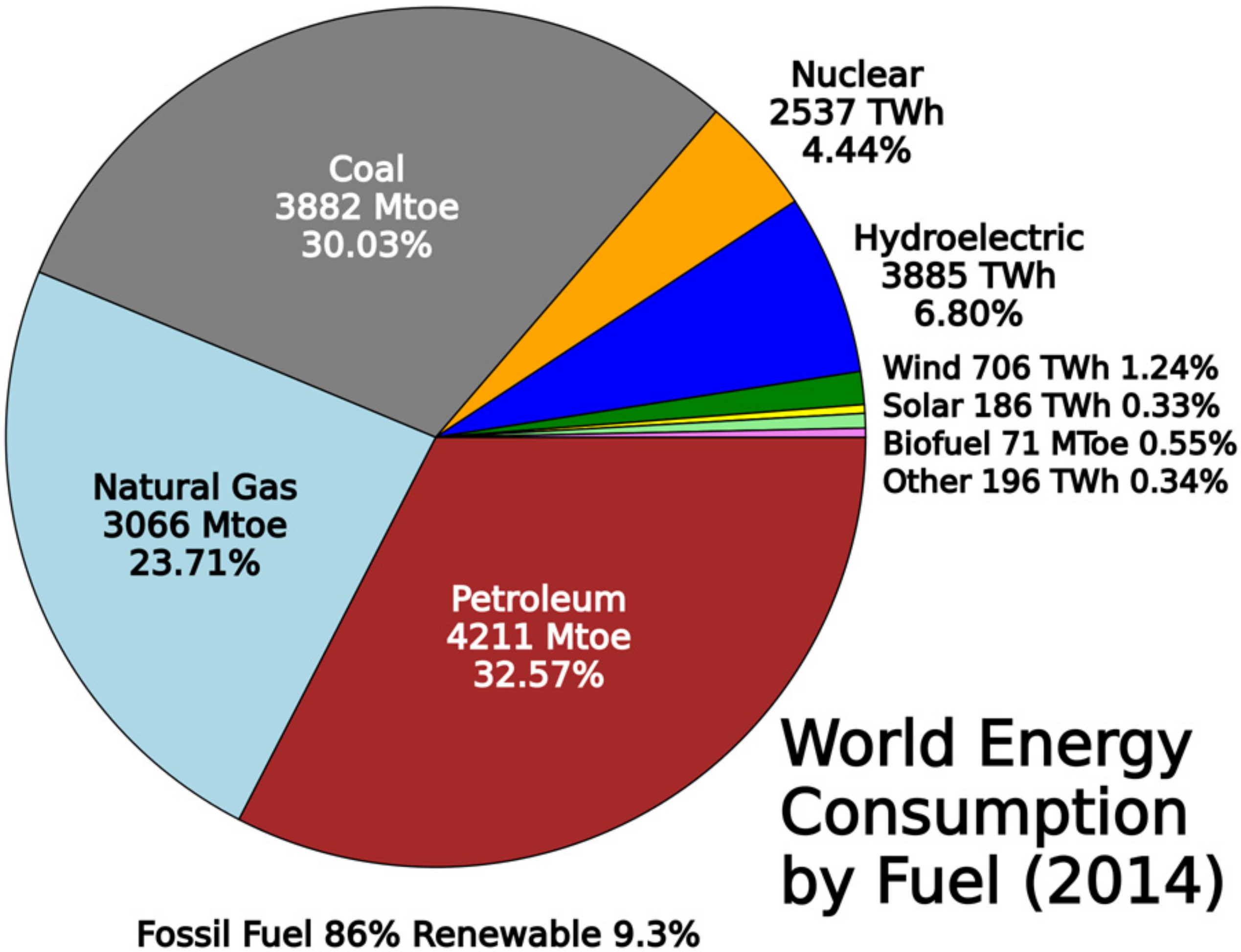


Figure 1 Source: https://upload.wikimedia.org/wikipedia/commons/thumb/d/de/World_energy_consumption_by_fuel.svg/2000px-World_energy_consumption_by_fuel.svg.png

Solar, wind, geothermal, tidal, biomass, and hydroelectric power are the renewable clean energy sources available on our planet. Although renewable energy sources are capable of providing sufficient energy to meet all our demand, they comprise but a small fraction of our energy resources we currently use (see Figure. 1). Solar energy, for instance, can supply 120 TW of energy while wind can provide 330 TW of energy, yet we use but a small percentage of solar energy (0.33%); and only 1.24% of wind as renewable energy resources. The principal barriers are economic as most renewable energy sources are more costly, less reliable and less efficient than traditional fossil fuels (MacKay 2009).

While these findings are true, it is equally certain that continued use of fossil fuels will have grave consequences to the environment and the sustainable existence of many species on the planet. Renewable energy is no longer a convenient option: it is quickly becoming a necessity. While there are many benefits to each of the renewable energy sources, this unit will focus on solar energy and its place in our energy future.

Photovoltaic Devices

The resolution to our questions of future energy needs depends on the availability of technologies that efficiently provide energy in a sustainable manner. Photovoltaic cells (solar cells) are useful devices that are used extensively to convert radiant energy to electrical energy. We have all seen them in our homes, in businesses and throughout our communities. Nano-crystalline dye-sensitized solar cells (DSSCs) are a variation of the traditional (and more expensive) p-n junction (silicon based) solar cells. They have been studied since the late 1990's and have proven effective in providing efficient conversion (greater than 10%) of radiant to electrical energy (Wang, et al. 2006). Most of my students are aware of photovoltaic cells as they are everywhere in our society but few are aware of how they work nor are they aware of the technology of the dye sensitized solar cell.

While the DSSC is promising to study, the cells used in industry or commercial settings use materials that are not safe to use in the high school classroom. A variation on the industrial DSSC was proposed by Greg Smestad and Michael Grätzel (Smestad and Grätzel 1998), that uses non-toxic materials to fabricate a DSSC. I will use the modified version in this unit on the chemistry of dye-sensitized solar cells.

Energy Science

My students normally study concepts associated with photosynthesis in their 9th grade biology classes but I feel it important to interconnect and elaborate those concepts in their 10th grade chemistry classes. In each of these processes, radiant energy is absorbed and then transferred by electrons (in the form of electrical energy) to sites where they do useful work (as in the case of photovoltaic cells) or to sites (as in the case of photosynthesis) where the electrical energy is transformed and stored in the chemical bonds of carbohydrates. Photosynthesis is the complex of chemical reactions that help autotrophs (terrestrial and aquatic) absorb, convert and store solar radiation in high-energy compounds that heterotrophic organisms use to meet their metabolic needs. Fossil fuels are the products of chemical processes that transform residual chemical energy in the remains of once living organisms into the energy rich compounds that power our modern industrial societies. While photosynthesis is the chemical reaction that captures the energy that sustains life on our planet, it is the sun that is the ultimate source of that energy.

This unit begins with an analysis of photosynthesis as it provides an opportunity to study and compare a natural system that captures and transforms energy with photovoltaic technologies that closely mirror those processes. It is particularly important as it exemplifies how electrons are used to transform light to electricity to stored chemical energy.

Electron Transfer

Electrons are negatively charged subatomic particles "located" in orbitals surrounding atomic nuclei. They play a central role in the formation of chemical bonds and in a variety of physical and biochemical processes that require the transfer / transport of electrical charge. The terms oxidation and reduction are important to this discussion as they refer to situations when electrons are transferred between atoms (or compounds). Oxidation occurs when atoms (or compounds) donate electrons; (the oxidized species carry a positive charge): reduction occurs when atoms (or compounds) accept electrons; (the reduced species carry a negative charge). Electron transfer is often accomplished by the transfer of a hydrogen atom: (H) or hydronium ion plus an electron (H^+ + e^-). Reduction occurs when hydrogen atoms (or hydronium ions plus electrons) are accepted by a chemical species; oxidation occurs when hydrogen atoms (or hydronium ions plus electrons) are donated. Oxidation and reduction (redox reactions) always occurs together: the substance being reduced accepts the electrons donated by the substance that undergoes oxidation. Electron transfer and redox reactions are principal processes in photosynthesis and in photovoltaic technology.

Photosynthesis

Photosynthesis is generally described by the following reaction:

$6CO_2$ (g) + $6H_2O$ (l) + *hn* -> $C_6H_{12}O_6$ (s) + 6 O_2 (g) (1)

Cellular respiration is the process through which living organisms metabolize carbohydrates to produce energy and carbon dioxide

$C_6H_{12}O_6$ (s) + $6O_2$ -> $6CO_2$ (g) + $6H_2O$ (l) + Energy (2)

While these reactions are generally representative of the processes of photosynthesis, they do not provide sufficient information as to how radiant energy is captured and transformed into stored chemical energy. To do so requires a more detailed description of the chemistry of photosynthesis.

Photosynthetic reactions are often divided into two phases: the light-dependent reactions, which must occur in the presence of light and the light-independent (dark) reactions that do not require light to proceed. The “light reactions” use solar energy to energize electrons donated by water molecules to produce chemical energy in the form of ATP (Adenosine triphosphate) and a reducing compound (Nicotinamide Adenine dinucleotide phosphate): NADPH. These compounds are then used in a series of reactions (known as the Calvin cycle) to reduce carbon dioxide and form carbohydrates. All of these reactions take place in the chloroplasts found in leaves and stems cells of green plants.

Chloroplasts are organelles containing an assemblage of thin sac-like membranes known as thylakoids that are stacked together into groups called grana. The enzymes and proteins needed to absorb and capture solar radiation are clustered together in photosystems that are embedded in the membranes of the thylakoid sacs. It is within the photosystems (I and II), that photoreceptors absorb solar energy and transfer it to electrons and compounds needed to complete the transformation of solar energy into the chemical energy stored within carbohydrates. These latter reactions (the dark reactions) take place in the semi-liquid fluid surrounding the thylakoids known as the stroma.

Transformation of Solar Energy

Chlorophylls (a & b) and the carotenoids are the photoreceptor molecules in green plants. Transformation of solar energy begins when a photon of light (of the “correct” energy and wavelength) interacts with one of these photosynthetic pigments. It is necessary to note that photons of light exist as discrete packets of quantized energy. Energy can be transferred to an atom (or molecule) if the photon’s energy matches the differences between energy levels within the atom (or molecule). This internal atomic structure determines the amount (quanta) of energy an atom (or molecule) can absorb; photons with the corresponding quanta of energy are the only ones absorbed: “as a result, every molecule has a characteristic absorption spectrum, the range and efficiency of photons it is capable of absorbing” (Raven and Johnson 2002 , 189).

The components of each photosystem carry out two distinct functions. Photoreceptor molecules (chlorophyll *a* & *b* and carotenoids) are held closely together by proteins in a tight membrane matrix (known as the light harvesting antennae complex). Each photosystem is positioned in the thylakoid membrane so as to maximize its ability to absorb light. When light (of the proper wavelength) hits the antennae complex, its energy is absorbed by a receptor molecule and passed along to successive receptors in the matrix until the energy reaches a reaction center. Reaction centers are pigment (mostly chlorophyll a) protein complexes that use the incoming light energy to excite an electron from a donor molecule. The excited electron is then passed from the chlorophyll to an acceptor molecule: a quinone. This action creates a charge imbalance: (a positive hole) within the chlorophyll and a negative charge in the reduced quinone. The chlorophyll then receives an electron from a water molecule (which now behaves as a positive species). The result of these two actions is the creation of an electrical potential between the oppositely charged molecules. At this point, the incoming solar energy has been transformed to electrical energy and the exited electron can proceed through the electron transport system.

The Electron Transport Chain

The Electron Transport System is composed of the two photosystems, enzymes, and two protein complexes embedded in the thylakoid membrane. Photosystem 2 (PS-II / P_{680}) is the first complex to absorb light and photosystem 1 (PS-I / P_{700}) to do so. The subscripts associated with each photosystem denote the maximum wavelength its pigments can absorb: thus PS-2 absorbs photons with a wavelength of 680 nm, while PS-1 absorbs those with a wavelength of 700 nm. The primary goal of the system is to use the electron's energy to drive the synthesis of ATP and NADPH. The synthesis of these molecules will provide the energy needed to complete the transformation of solar energy into stored chemical energy. Water molecules and a complex of manganese and calcium ions enzymes are bound to the reaction center of PSII. When light energy reaches the reaction center, it drives the splitting of the water molecules (Barber 2012). This reaction provides the electrons that are excited within the reaction center along with the hydrogen ions (H^+) used in the chemiosmosis mechanism of ATP and NADPH synthesis. The water-splitting reaction is as follows:

$2\ H_2O\ (l) \rightarrow 4H^+ + 4e^- + O_2\ (g)$

Oxygen gas escapes as a byproduct of the light-dependent reactions.

Electrons generated in this reaction are donated to the reaction center where they are excited and used to reduce quinone to plastoquinone). Plastoquinone interacts with a complex (cytochrome b_6-*f*) that uses the energy of the electron to pump a proton from the stroma into the thylakoid lumen space. Protons can exit only through protein channels in the thylakoid membrane. As protons exit through these proteins (known as ATP synthase channels), a phosphorous atom is added to ADP forming the high-energy compound ATP. This process known as chemiosmosis completes a transformation of light to electrical to chemical energy.

The electron from PSII does not leave the matrix; rather it travels to the second photosystem PS-I / P_{700} where it is once again energized by incoming light energy. Energized electrons (two at a time) will interact with ferrodixin (an iron- sulfur protein) and exit the thylakoid through the membrane bound enzyme $NADP^+$ reductase which helps reduce $NADP^+$ to NADPH. The ensuing reactions (the Calvin Cycle) take place in the stroma where NADPH (with energy supplied by ATP) reduces carbon dioxide to a carbohydrate (Raven and Johnson 2002). This last step completes the transformation of light to electrical to chemical energy. The chemical reactions of the Calvin Cycle will not be analyzed as my goal is to explore the relation between the reactions the in light reactions of photosynthesis and photovoltaic cells. The details of the mechanisms by which carbon is reduced are beyond the scope of this review.

Chemistry of Photovoltaic Cells

Photovoltaic cells are devices that absorb and transform radiant energy into electrical energy. Their technology mirrors (in many aspects) the reactions in photosynthesis that transform radiant energy into electrical energy. The primary difference is that the electrical energy produced is (in most cases) used to do work, rather than being stored. The principal materials in solar cells are semiconducting elements (or compounds) that are capable of establishing an electrical potential between layers of differing polarity. There are many elements and compounds that can be used to create these devices; of these silicon, (the first to be used) remains as the more commonly used semiconducting component in used PV cells (Surek 2005).

Semiconductors

Semiconductors are elements or combination of elements whose resistivity and hence conductance is between that of conductors and insulators. The resistivity of conductors is between ~10^{-8} and 10^{-12} W cm: insulators ~10^{9} and 10^{19} W cm, while that of semiconductors varies between 10^{-5} and 10^{2} W cm (silicon has a resistivity between 0.1 and 60 W cm) (Giancoli, 2002). Semiconductors are intermediate between insulators and conductors because their band gap (the energy difference between the highest level of their valence band and the lowest level of their conductance band) is relatively small. Molecular orbital theory states that as atoms bond, each type of atomic orbital forms a bonding and non-bonding molecular orbital. Thus, whenever n atoms bond, n -bonding and n -non-bonding molecular orbitals are formed.

The Band theory of solids, suggests that as these large numbers of atoms come together (as in a lattice structure), the discrete energy levels of the two types of molecular orbitals merge together to form bands. In solids, the highest occupied energy levels are referred to as the valence band (highest occupied molecular orbitals), while the conduction band is the lowest unoccupied molecular orbitals.

The difference in energy between the two bands is referred to as the band gap, and the energy required for an electron to move between the two bands is referred to as the band gap energy. The conductive properties of insulators, conductors, and semiconductors can be understood from the difference in their band gaps. Table 1 compares the band gaps and band gap energies of conductors, insulators, and semiconductors (germanium and silicon).

Table 1: Band Gap and Band Gap Energy of Conductors, Insulators, and Semiconductors

Material	Band Gap (eV)	Band Gap (Joules)
Carbon	5.5	8.8 E –19
Silicon	1.11	1.76 E –19
Germanium	0.66	1.0 E –19
Tin	0.11	1.76 E –20

Source: http://www.owlnet.rice.edu/~chem152/lecture/Reading/semibands.html

As one can note from these data, the band gap (and band gap energy) for conductors is much smaller (0.11 eV), than that for insulators (5.5 eV). The high band gap of insulators makes it nearly impossible for electrons in these insulators to move from the valence band to the conduction band. The corresponding values for semiconductors (silicon & germanium) are between the two extremes, which permit these elements to function as conductors or insulators.

The relatively small band gap energy for semiconductors makes them suitable for PV devices because the energy of photons is between 3.5 eV (ultraviolet radiation) and 0.5 eV (infrared radiation). The range in the visible spectrum is smaller: 3.0 eV (violet light) to 1.8 eV (red light). Photons possessing energy within these ranges are able to excite electrons in the valence band of the semiconductor and move them into the conducting band from which they can move into a circuit (Lewis and Crabtree 2005). This excitation of an electron into the conduction band is similar to the excitation of the electron in the photosystems of photosynthesis.

Semiconductors are well suited for semiconductor electronics because their resistivity can be altered by the addition of impurities (either pentavalent or trivalent atoms) to their lattice. The process of adding impurities to an intrinsic (pure) semiconductor (silicon or germanium) is referred to as doping (the impurities are called dopants).

Each element has a characteristic number of valence electrons used in the creation of molecular bonds. Bonding occurs as atoms "share" their valence electrons.

A typical semiconductor such as silicon requires four electrons to complete its valence shell. If silicon is bonded with an atom with less than four valence electrons (such as Boron), a "hole" will be created as it only has seven of its required eight valence electrons. This missing electron is referred to as a positive "hole." This material given its deficiency in negative charge is referred to as "p" (positive) substrate. If the silicon is configured with an atom that has five valence electrons (such as Phosphorous), the material will have an excess (one extra electron) negative charge and will be referred to an a "n" (negative) substrate. When sunlight strikes the PV cell, electrons promoted into the n doped region, while the positive holes "move" into the doped region. The separation of charges establishes the electrical potential of the cell. Silicon is thus ideally suited for integrated circuits as it is quite easy to create areas of differential electrical properties by bonding it with other group 13 or group 15 elements.

A variety of PV technologies have developed since their advent in the late 1970's. Since that time their efficiency has improved dramatically (some multijunction cells have over 40 % efficiency) (Surek 2005). As efficiencies have improved, the cost (as a function of efficiency) has lowered; however, some technologies (single crystal silicon cells) remain more expensive than others. Cost and efficiency will ultimately determine the extent of our usage of PV cells. Nate Lewis (Lewis and Crabtree 2005), suggests that costs (below \$0.40 / W_p) would "result in massive implementation of solar energy systems in the energy system of the U.S. and globally" (Lewis and Crabtree, 19).

Such a cost breakthrough would also represent a major advance in using solar energy to alleviate the anticipated future problems associated with energy supply, energy security, and unacceptable levels of CO_2 production (ibid 19).

Dye Sensitized Solar Cells

In the early 1990's Michael Grätzel and Brian O'Regan proposed a new solar cell technology (the dye-sensitized solar cell: DSSC), that would lower the cost of existing, expensive PV devices. They proposed a new design for a photovoltaic cell.

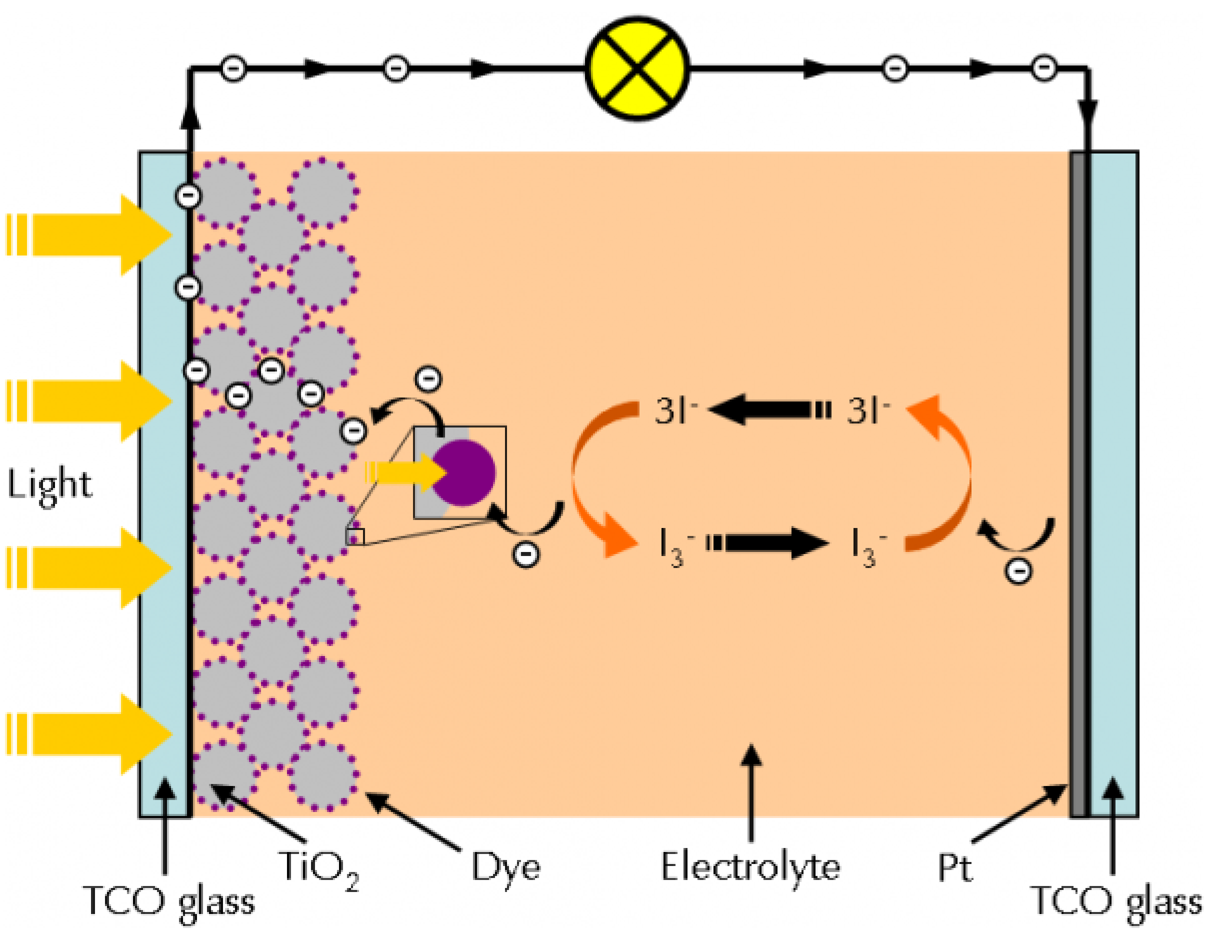
The device is based on a 10 mm thick, optically transparent film of titanium dioxide particles a few nanometers in size, coated with a monolayer of a charge transfer dye to sensitize the film for light harvesting (O'Regan and Grätzel 1991, 773).

While the DSSC is promising to study, the cells used in industry or commercial settings use materials that are not safe to use in the high school classroom. A variation on the industrial DSSC for high school students was proposed by Greg Smestad and Michael Grätzel (Smestad and Grätzel 1998), that uses non-toxic materials to fabricate a DSSC. I will use the modified version in this unit on the chemistry of dye-sensitized solar cells.

The Dye Sensitized Solar Cell (High School Version)

This adaptation of the Dye Sensitized Solar Cell is perfect for a high school classroom because it is relatively easy to build, is exceptionally durable, and uses readily available, inexpensive materials (TiO_2, an (I^- / I_3^-) electrolyte solution, dyes from berries, and conductive glass) (O'Regan and Grätzel 1991). The DSSC relies on electrons in a dye matrix to absorb and capture radiant energy. The energy is transferred to an electron that becomes energized and is then injected into the conduction band of the titanium dioxide semiconductor. The electron-deficient dye is reduced by iodide (I^- in the electrolyte), back to its original state. The energized electron leaves the semiconductor (at the anode) and travels through the circuit where it does useful work before returning to the counter electrode (the cathode). The returning electron is used to reduce triiodide (I_3^-) ion. The triiodide then reduces back to iodide so that it can regenerate the dye matrix (Naseerudin, Baranoff and Grätzel 2011) (See Figure 2).

Figure 2: Dye Sensitized Solar Cell



Source: http://www.gamry.com/application-notes/physechem/dssc-dye-sensitized-solar-cells/

Using electrons to capture and transfer energy (electron transfer) occurs in a variety of biological and physical systems. Electron transfer of energy occurs in biology: (the electron transfer chain in the mitochondria during cellular respiration) and in environmental science: (the electron transfer chain in the thylakoid membrane of chloroplasts during the light reactions of photosynthesis).

Electron transfer is the basis of the energetics that drive the processes of life on earth (Smestad and Grätzel 1998, 752).

The science of the DSSC is particularly important to me because it interconnects environmental science, chemistry, biology and physics. The teaching of electron transfer (and its related concepts) will provide the opportunity to reinforce the interconnectedness of the sciences to my students.

Unit Introduction

Each day of the unit is framed by an essential question that students will need to answer in their unit journal. The answer to these questions will serve as an ongoing formative assessment of student progress. Following the essential question, the day's strategies are outlined in narrative form. A discussion of the day's content is provided in the direct instruction section, followed by an explanation of the classwork in the class activity section. Standards used are primarily from the Next Generation Science Standards, however the common core literacy standards are used to inform assignments that require students to engage in research or writing.

Day One: Energy in our Everyday Lives

Essential Questions: What is the role and importance of energy in our lives? What is the ultimate source of energy on our planet?

Objectives: To evaluate the role and importance of energy in society. To describe describe the transformations of energy and analyze the role of solar radiation in the various forms of

Standards: HS-ESS3-1 & HS-ETS1-3

Strategies: This class will introduce the concept of energy through a written analysis of the various forms of energy used in our daily lives. Students will describe the role of energy in their lives (and in society), and the major forms of energy they (and their family members) use during a typical day. The goal of the lesson is to engage students in an analysis of the forms and transformations of energy and to then to lead a discussion on the importance of energy in our lives.

Direct Instruction: Students should already know that there are two broad categories for energy: kinetic and potential (chemical and gravitational potential energy). They should also be familiar with the various forms of energy (solar, wind, electrical, geothermal, tidal, nuclear, and chemical energy), that help us perform useful work in our lives. While energy can be transformed from one form to another, students should understand that solar radiation is the ultimate source of energy in their lives. I will ask students to determine the "origin" of given forms of energy that they use: the goal of our discussion is to establish solar radiation as the primary source of energy (with the exception of geothermal, tidal, and nuclear energy) on our planet.

Classroom Activity: (Written analysis): Use the guided analysis questions to describe the major sources of energy used in your everyday life. Why is energy important in your life? Where does that energy come from? Name the energy resources used to generate the energy.

Materials: Written activity guided questions (in student resources) and student journals.

Day Two: Energy Resources and the Environment

Essential Questions: What are our major energy resources? How does our use of energy affect the planet's ecosystems?

Objective: To describe the major energy sources and to evaluate how their use affects the environment.

Standards: HS-PS3-2 Energy & HS-ESS3-1 & ESS3-5

Strategies: The class will engage in a review of the transformations of solar energy into stored potential energy in fossil fuels. We will then explore the reactants and products of the combustion reactions of hydrocarbons and how increased carbon dioxide emissions are implicated in climate change. The class will then view a video on greenhouse gas emissions which will help them evaluate the effect of these emissions on the environment.
Direct Instruction: After reviewing the formation of fossil fuels, I will analyze the balanced combustion reactions of coal, methane, and octane and why the emissions are called greenhouse gases. I will introduce the concept of greenhouse gases and how they regulate the earth's temperature.
Classroom Activity: Students will note the components of chemical reactions and describe the products / reactants (greenhouse emissions) of the combustion of hydrocarbons. Students will be shown a graph that shows the relation between increased CO_2 emissions and global temperatures. They will then view a short video on the earth's natural greenhouse effect and analyze how increased carbon emissions affect the environment. They will answer a set of analysis questions on the greenhouse effect and then write a brief summary paragraph on how our increased use of fossil fuels affects the environment.

Materials: Greenhouse effect video, video analysis questions (in student resources), CO_2 emissions vs. temperature graph, and student journals. Access to video in teacher resources.

Day Three: Ecological Footprint.

Essential Questions: How does our personal use of energy affect the environment? How can we alter our behavior to limit our effect on the environment?

Objective: To analyze and evaluate how our personal energy usage affects the environment. To propose ways to conserve energy and reduce our carbon footprint.

Standards: HS-ESS3-1; & ESS3-4; HS-ETS1-3

Strategies: Industrialized societies produce massive amounts of CO_2 emissions. Students will then be asked if they know their contribution to global CO_2 emissions. The class will challenge them to evaluate their ecological footprint and (more importantly) to begin to analyze how they can reduce their carbon footprint.
Direct Instruction: After the opening discussion, I will introduce the concept of ecological footprint (and its component footprints).
Classroom Activity: Students will take an online ecological footprint analysis: (the results are broken down into a variety of footprints (carbon, food, energy, and waste). Students will be asked to analyze how focus on those activities that increase CO_2 emissions. Students will be asked to write a brief summary paragraph on the activity and to propose at least five ways they can begin to conserve energy and reduce their carbon footprint: (This will be an ongoing activity as we will revisit this analysis several times during the unit. The goal is to lower their overall footprint by at least 50% or more.

Materials: Computer cart, internet access, and teacher subscription to Global Footprint Network (Instructions are in teacher resources). Student ecological footprint analysis questions in student resources.

Day Four and Five: Increased CO_2 emissions and Climate Change

Essential Questions: What are projected effects of climate change? How will increased temperatures affect the earth's various ecosystems? How will increased temperatures affect human societies?

Objective: To evaluate the effect of increased temperatures on the earth's ecosystems and human societies.

Standards: CCSS.ELA-Literacy.RST.11-12.9: HS- ETS3 & HS-ESS3-5

Strategies: This class begins a discussion that will frame the entire unit. The underlying motivation of this unit is to make students aware of the urgency of climate change and to encourage them to consider how their practices (now and in their future lives) affect the environment. The goal of this class is to have students discover for themselves the impending consequences of climate change. In order to accomplish this, they will engage in a collaborative web quest that explores the evidence for and consequences of climate change.
Direct Instruction: The class begins with a recap of carbon emissions and their effect on global temperatures, followed by a viewing of the 2007 AAAS video on climate change. Following the video, I will lead a brief class discussion on the various ways that increasing global temperatures can affect ecosystems, biomes, living organisms, climate, and human societies; (other effects may be suggested by students). The discussion will serve as introduction to the collaborative group research activity on climate change.
Classroom Activity: Students will divide into groups of four. Each group will analyze a differing aspect of climate change. Students will first prepare their own set of research questions and then log on to onto the Koshland Science Museum Webquest© site. The webquest covers the following topics: climate vs. weather, the greenhouse effect, causes and effects of climate change, and ways to mitigate the projected effects. Students will need two period to complete and present their findings. A presentation rubric should be developed by the class to assess each group's work. Each group's research questions and the unit essential questions can serve as assessment guides for each presentation. Each student's research findings should be written into their unit journal.

Materials: Kochland Museum Webquest site (URL in student resources): Computer cart, additional websites on climate change if needed: (URL in teacher resources), and student journals.

Day Six: Carbon Cycle

Essential Questions: How does solar energy enter the ecosystem? How is carbon dioxide captured and sequestered in ecosystems?

Objective: To analyze processes that cycle solar energy and carbon dioxide in natural systems. To evaluate human actions that disrupt the carbon cycle.

Standards: HS-LS2-3 & HS- LS2-5

Strategies: The class will explore the "natural" carbon cycle, focusing on processes that trap / sequester CO_2 and those that release it. The discussion will review photosynthesis and combustion reactions (including cellular respiration) as central processes in the carbon cycle. An important component of this analysis will be on the ways that human activities disrupt the cycle and increase atmospheric carbon dioxide levels.
Direct Instruction: I will ask students to review their understanding of photosynthesis and respiration (noting how CO_2 is captured in carbohydrates and sequestered in fossil fuels and biomass). I will show the class a video that analyzes the processes that cycle carbon in terrestrial / aquatic biomes and in the atmosphere. The focus will be on the processes that maintain the carbon balance and those human activities that disrupt the balance.
Classroom Activity: Students will use a set of guided questions to analyze the video of the carbon cycle. Students will need to include the chemical reactions of photosynthesis and respiration in their analysis. Students will be asked to determine where (and how) the cycle is disrupted by human actions: (they will also need to include the combustion reactions of fossil fuels in their analysis).

Materials: Video of the carbon cycle (URL in teacher resources), video analysis questions and unit journals.

Day Seven- Eight : Photosynthesis

Essential Questions: How is light energy transformed into electrical energy? What is the role of the electrons in this process?

Objective: To analyze how solar radiation is transformed into chemical energy during photosynthesis.

Standards: HS-LS1-5 & HS- LS1-7

Strategies: This class will build on student's understanding of photosynthesis and focus on the role the electrons in the transformation of light into electrical energy. The class will begin with a review of atomic structure and the charges of the subatomic particles. The class will also need to explore the relationship between light energy, color and wavelength. Understanding this relationship is essential to our analysis of the photosystems in photosynthesis as well as the absorption of light in the dye sensitized cell.
Direct Instruction: I will show the class the structure of the atom, and review the charges and location of protons, electrons and neutrons (using the planetary model of the atom). I will then show the class a diagram of the electromagnetic spectrum and discuss the relationship between energy of light, wavelength, and energy. Although students have already learned this material, time may be needed to fully review this content. Once the review is completed, I will show the class the absorption spectrum of the chlorophylls and relate the colors absorbed to the wavelength of the photons absorbed in the two photosystems. We will then look at a diagram of the two photosystems in the thylakoid within plant chloroplasts. I will focus on the processes that excite electrons in each of the two photosystem and how the passage of electrons transforms solar radiation to the electrical potential that drives the chemiosmotic synthesis of $NADPH^+$ and ATP within the thylakoid lumen. I will introduce the concepts of oxidation / reduction as part of the process (chlorophyll *a* is oxidized to produce the electrons needed, while CO_2 is reduced to produce carbohydrate.
Classroom Activity: Given the need to review prior knowledge, this day's work will require two days to complete. Students will complete a set of review questions on atomic structure and the electromagnetic spectrum. Once completed the analysis of the photosystems can begin. To analyze the photosystems, students will complete a set of analysis questions and diagram the processes of the two photosystems.

Materials: Diagram of the photosystems, and guided analysis questions.

Day Nine: Light energy, color, and photovoltaic cells.

Essential Questions: What is the relationship between the color of light and energy?

Objective: To describe the difference between the processes in natural photosynthesis and those in photovoltaic cells.

Standards: CCSS.ELA.-Literacy.RST.11-12.3: HS-PS1-1; HS-PS3-3

Strategies: This class introduces photovoltaic cells as a technology that transforms light energy into electrical energy. Students will review their understanding of the photosystems in photosynthesis and relate those processes to the excitation of electrons in solar cells. The principal difference being that solar cells use the electrical energy directly. The class will begin with a review of the electromagnetic spectrum and the two photosystems in photosynthesis.
Direct Instruction: I will first review the areas of the electromagnetic spectrum and explain the relationship between color, energy, and wavelength. Students will view a diagram of the absorption spectrum of the chlorophylls and relate the colors absorbed to the wavelength of the photons absorbed in the two photosystems in photosynthesis. We will then review how light energy is transformed into electrical energy in the photosystems. I will then show the class a dye sensitized photovoltaic cell and explain that the cell is performs a similar transformation of light energy into electrical energy.
The dyes are similar to the chlorophylls as they absorb light of a specific wavelength and energy. I will then show the class the materials used to make a dye sensitized cell. I will explain the properties of semiconducting TiO_2 compound that is used in the cells, as well as the conductive properties of the cell plates. This will serve as a review of the differences between conductors, semiconductors and insulators. I will also show the class how to use the multimeters that are used throughout the lab. This will serve as an introduction to our lab on dye sensitized cells.
Classroom Activity: Making the DSSC is relatively simple, however the preparation of the TiO_2 semiconducting paste is somewhat complicated and time consuming. Thus I will prepare the paste before the class. In this class students will prepare the conducting plates, apply the TiO_2 paste and begin the annealing process.

Materials: Diagram of EMS spectrum, materials for DSSC lab (in Activities Section), DSSC lab manual (in teacher section),

Day Ten- Day Twelve: Dye Sensitized Solar Cell

Essential Questions: How is light energy transformed in a solar cell?

Objective: To analyze the processes that transform light energy to electrical energy in a DSSC.

Standards: CCSS.ELA.-Literacy.RST.11-12.3: HS-PS1-1; HS-PS3-3

Strategies: Students will follow the lab procedure as outlined. They will be provided materials to build and test a DSSC.

Materials: Materials and procedure for lab (appendix B: Lab Activities), student analysis questions (in student resources), additional resources in teacher resources.

Unit Summary: Constructed Response

Essential Questions: Why should we use renewable / carbon neutral energy resources? What is our responsibility to the environment?

Objective: To evaluate the impact of energy use.

Standards: CCSS.ELA-Literacy.RST.11-12.9: HS- ETS3 & HS-ESS3-5

Strategies: This class discussion will provide students the opportunity to propose their responses to various questions raised during this unit. The goal of the discussion is to provide a forum in which they can freely discus their position on these questions. What is their position of energy use given the economic realities and potential climate changes? The goal of the class is to propose ways that we can use energy in ways that protect the environment

Direct Instruction: I will function as moderator in this discussion. Students will take the lead focusing on the issues they deem pertinent. The class will decide the format and guidelines for their final summary essay. It is my hope that their essays will address their perspectives on climate change, their sustainable practices (now and in the future) that will safeguard the environment, and how they will advocate for responsible environmental policies.

Classroom Activity: Discussion Format.

Materials: Unit Journals.

Appendix A

Student Resources: Guided Analysis Questions

These analysis questions are presented as guides that facilitate analysis and discussion. Teachers should view the videos prior to instruction and edit these questions to suit your classroom population

Energy in Everyday Life Essay Prompts: Day 1

1. Define energy in your own words. Why is it important in your life?
2. What are the forms of energy that you use daily? Which form is most important?
3. Describe at least five important uses of energy in your life?
4. What is the source of energy on our planet?

Greenhouse Effect Guided Questions: Day 2

1. What are greenhouse gases? Name and describe them
2. Why do we refer to them as greenhouse gases? What is their function?
3. Explain what happens to solar radiation when it reaches the earth.
4. What happens to the absorbed energy?
5. What would happen if we did not have greenhouse gases?
6. What is the earth's "natural greenhouse effect"?

7. What happens when we increase the concentration of greenhouse gases?
8. What should we do to minimize this effect?

Ecological Footprint Guided Questions: Day 3

1. What is the meaning of the ecological footprint?
2. Which of your footprints was the largest?
3. What was your carbon footprint?
4. Describe how your use of energy affects your footprints.
5. Are you living a sustainable life style?
6. For each one of your footprints, describe at least two practices that you could change in order to lessen your ecological footprint.

Koshland Science Museum Student Webquest Day 4-5

Webquest available at: https://www.koshland-science museum.org/sites/default/files/uploaded-files/Global%20Warming%20Webquest.pdf.

Webquest used as Courtesy of the Marian Koshland Science Museum

of the National Academy of Sciences

Carbon Cycle Video Viewing Guide: Day 6

1. What form of energy is continually input into the earth system?
2. What happens to this energy once it enters the ecosystem?
3. What is the role of autotrophs in the carbon cycle?
4. Describe the reactants and products in the photosynthesis reaction.
5. How is glucose stored and used? What is biomass?
6. What compound does the combustion of plants release back into the atmosphere?
7. What compound does the combustion of fossil fuels release into the atmosphere?
8. What is the meaning of the word sequestered? What is the meaning of the phrase “sequestered in decomposing plant / animal tissues” for millions of years?
9. What is oxidative metabolic respiration? What compound is released into the atmosphere?
10. What is the role of decomposers? What compound do these organisms release?
11. How is carbon cycled through the hydrosphere?
12. How is CO_2 sequestered in the biosphere?
13. What natural processes release it back into the biosphere?
14. How is the carbon balance maintained?
15. How do human actions disrupt this cycle?

DSSC lab Analysis Questions:

1. Why did we use conductive glass for the electrodes? Which subatomic particles were able to move through them?
2. When the dye lost electrons was it oxidized or reduced? What happened at the counter electrode?

3. Why did we dye the white TiO_2 paste? What would have occurred if it had remained white? (Why do you remain cooler when you wear white clothes on a hot day?)
4. Compare the processes in the DSSC with those in the photosystems of photosynthesis. How are the two processes similar how are they different? Describe the transformations of energy in the two systems.
5. Describe the process in the DSSC. What provides the energy to excite the electrons? Where do the electrons come from? Where do they go? Are they “lost”? How do they return to the dye matrix?

Teacher Resources

Greenhouse Effect Video Day 2: Stable URL. Available at:
https://www.youtube.com/watch?v=3JX-ioSmNW8&feature=youtu.be.

This video is the third in a seven part series on climate change available from the Academies of Natural Sciences at:
http://nas-sites.org/americasclimatechoices/videos-multimedia/climate-change-lines-of-evidence-videos/

Global Footprint Network Day 3: Subscription is needed to take Ecological Footprint quiz: Network is located at: http://www.footprintnetwork.org/en/index.php/GFN/: Choose classroom level subscription: Subscription is by donation. Membership provides classroom access for ecological footprint analyses. Students will be able to measure various footprints online and have their scores archived for future reference. Membership also provides weekly newsletters from the network, along with other resources to study and promote sustainable activity.

AAAS Video on Climate Change: Available at: https://www.youtube.com/watch?v=_nZjrPoAlbU

This video introduces students to the debate on climate change. It details the effects of human activities (deforestation, excessive greenhouse gas emissions) on global temperatures and how increasing temperatures will affect our climate and all life on the planet. The video poses a challenges us to examine how our use of energy can ameliorate (or worsen) our current crisis.

Koshland Science Museum Webquest: Day 4 – 5

Koshland Science Museum Teacher Resources available at:
https://www.koshland-science-museum.org/sites/default/files/uploaded-files/Global%20Warming%20Webquest%20Instructions%20for%20Teachers_0.pdf

Webquest used as Courtesy of the Marian Koshland Science Museum

of the National Academy of Sciences

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This site contains background information on the Webquest, along with evaluation rubrics, collaborative group assignments, standards used in the webquest, and additional websites, and resources that can be used to answer more specific and technical student inquiries. Note: additional websites can be included in the webquest if they are needed to answer more specific or technical questions posed by students: these websites can be found in the teacher resources page of the webquest site.

Global Climate Change Resources from AAAS located at:
http://www.aaas.org/news/global-climate-change-resources

Many additional resources on climate change including: a second climate change movie

Ways to stop global warming, speeches by climate change activists, and a variety of news reports on climate change.

Carbon Cycle Video: Day 6

Video located at: https://www.youtube.com/watch?v=d70iDxBtnas

The video focuses on the processes that trap carbon dioxide through photosynthesis, those that release it (cellular respiration, combustion, decomposition), and those that sequester it in fossil fuels. The video explains how carbon is cycled and stored in aquatic, terrestrial biomes and in the atmosphere and how the interaction of processes that capture and release carbon dioxide maintain the earth's carbon balance.

Photosystems in Photosynthesis Day 7-8 : Stable URL: Available at:

http://faculty.southwest.tn.edu/rburkett/GB-1%20p27.jpg

Diagram of EMS: Day 9

Stable URL: Available at: http://www.astronomersgroup.org/images/EMspectrum.jpg

Dye Sensitized Solar Lab: High School Version: Day 10-12

Lab adapted (by permission) from Center for Chemical Innovation in Solar Fuels. Annelise Thompson, Editor. Dye-Sensitized Solar Cells, *Juice from Juice,* 2016. Lab manual located at: http://ccisolar.caltech.edu/files/03-DSSC-HS.doc

Additional DSSC Laboratory Guidelines, videos, and extension activities are available from the University of Wisconsin Madison University MRSEC: http://education.mrsec.wisc.edu/289.htm

Appendix C: Dye Sensitized Solar Cell Lab

Materials

Conductive FTO glass *

Nanocrystalline TiO_2 powder *

Potassium Iodide Electrolyte solution*

Graphite pencil *

Binder Clips *

Leaves from plants (chlorophyll dye)

Dilute acetic acid (0.1mL diluted in 50 mL deionized water)

Mortar and pestle

Multimeter

Dishwashing soap

Ethanol

Alligator clips

Hotplate

Transparent tape

Water wash bottle

Berries (Black, Blue, Raspberries)

Materials with an asterisk are available in the Nanocrystalline Solar Cell kit from the Institute for Chemical Education: http://ice.chem.wisc.edu/Catalog/SciKits.html

Preparation of TiO_2 Semiconducting paste

1. Weigh 6 g of TiO_2 powder into a mortar
2. Add powder to 9 mL of dilute acetic acid (~ pH 2.5)
3. Slowly add the acid in 1 mL increments to the powder while grinding with a pestle.
4. Make certain a uniform suspension forms before adding additional acid.
5. Continue adding acid in 1 ml increments, grinding carefully until a lump free suspension is formed (approximately 30 minutes). Resulting suspension should have the consistency of paint.
6. Once finished add a drop of dishwashing liquid to the suspension: Do not grind after the soap is added. Transfer the paste to a syringe: cover end with paraffin to prevent drying out.

Preparation of Conductive Electrode

1. Determine the conductive side of the glass using a multimeter. The conductive side will register resistance between 25 and 30 ohms.
2. Use transparent tape to tape the glass to a clean sturdy surface. Use the tape to make a border around 3 sides of the glass: two sides should have a border of 1 mm, the top of the glass will have a 4 mm border (this is where the alligator clips will be attached): the fourth side has no border. The pieces of tape should help secure the glass to the work surface. Carefully clean the glass with a few drops of ethanol
3. Place a small amount of TiO_2 paste on the glass and immediately spread the paste with a glass rod to

produce a thin uniform coating. Allow the electrode to dry.

4. Once dry place the electrodes on a cold hot plate and set it to high. This will sinter the electrode. The electrode will turn brown then back to white. The process is complete after ~ 30 minutes.
5. Turn the hot plate off and allow the electrodes to cool fully before handling.
6. Use a second conductive glass to prepare the counter electrode. Find the conductive side; then use a graphite pencil to make a uniform coating of graphite on the entire glass.

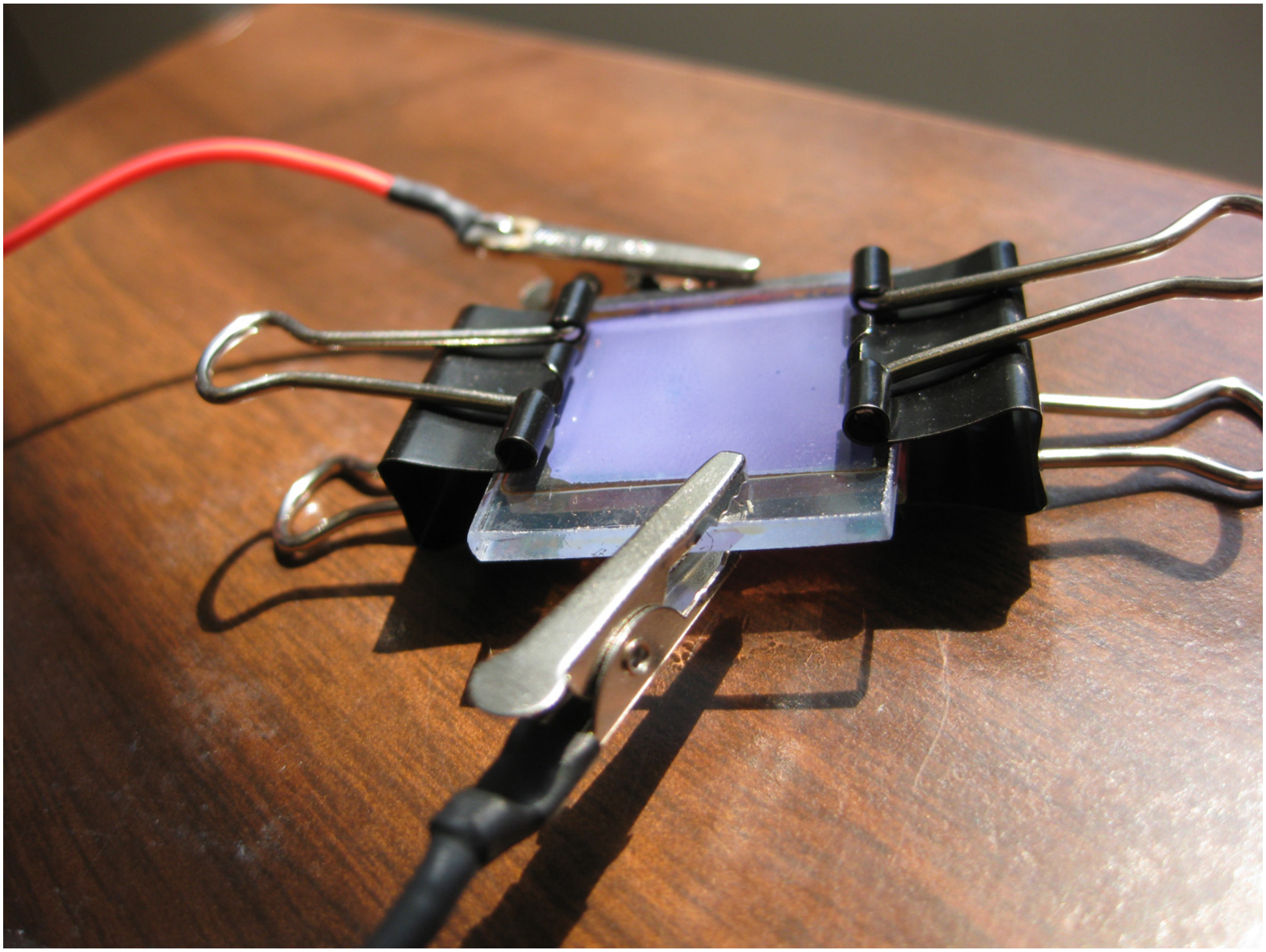
Making the DSSC cell

1. Prepare the dye by crushing a few berries and ~ 2 mL of deionized water in a small plastic bag.
2. Carefully remove the tape from the white electrode, then place it in the bag with the berries. Wait for the dye to take effect.
3. Remove the electrode with a pair of tweezers: wash carefully with water then ethanol. Let the electrode dry.
4. Repeat this procedure with the dyes from other berries: when all electrodes are dry proceed to the next step.

Measuring Voltage

1. Using alligator clips, connect a multimeter to the edges of the electrodes: (attach the the negative (black wire) of the multimeter to the TiO_2 electrode): the positive (red wire) to the counter electrode.

Figure 3: Dye Sensitized Solar Cell:



Source: http://www.nisenet.org/sites/default/files/images/catalog/5553/dssc.jpg

Used by permission of University of Madison Wisconsin MSREC Education Group:
http://education.mrsec.wisc.edu/289.htm

2. Shine a light source on the cell then measure and record the voltage of your cell.

3. Compare the voltage of your cell with others in your group.

Once finished complete the analysis questions

Extension Activities

1. Connect cells in series to power small electronic devices.
2. Use chlorophyll extracted from leaves as a dye.
3. What would happen if colored rather than white light were used as an energy source?

Standards Narrative

COMMON CORE SCIENCE LITERACY STANDARDS:

Source: http://www.corestandards.org

CCSS.ELA-Literacy.RST.11-12.9 Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of process, phenomenon, or concept, resolving conflicting information when possible.

CCSS.ELA-Literacy.RST.11-12.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

The common core standards focus on literacy skills; thus they are relevant for classwork that focuses on research or essay assignments. Standard RST.11.12.9 is used in the webquest on climate change as students need to use information from various sources to complete their research. RST.11-12.3 is relevant to laboratory activities as it focuses on the skills needed to successfully complete a laboratory activity.

NEXT GENERATION SCIENCE STANDARDS:

Source: http://www.nextgenscience.org/

There are three categories of standards in the unit: physical science, life science and engineering design standards. Life science standards are used to inform activities that explore biology concepts in the unit.

HS-LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.

Standards HS-LS1-5 & HS- LS1-7 are used in the analysis of photosynthesis and cellular respiration. LS1-5 is especially useful as it focuses on the transformation of light energy into chemical energy of carbohydrates. LS1-7 provides a context to explore cellular respiration as a process that converts the stored energy in food.

The following standards HS-LS2-3 and HS-LS2-5 are used to inform the analysis of the carbon cycle. They are used to establish the ways that the carbon cycle is maintained and how human actions disrupt the balance of carbon stores.

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

HS-LS2-5. Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

Physical science standard HS-PSS3-3 focuses on the skills needed to build the DSSC as a device that transforms light into electrical energy. An important aspect of this standard is that is asks students to refine their device. This is important to the unit as students will be asked to consider ways to improve the efficiency of their DSSC. Standard HS-PS1-1 is used in the lesson on semiconductors, insulators, and conductors as they are located in specific regions of the periodic table.

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

The earth space standards are essential to this unit as they address environmental issues that arise as a result of human activity. They are especially relevant to a unit that explores climate change and its projected impact on human life. HS-ESS3-1ask students to analyze how our actions affect the environment, while HS-ESS3-4 asks us to consider solutions that will ameliorate the consequences of our actions. These standards frame the entire unit.

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

Since evidence is needed to support the claim that human actions are responsible for climate change, HS-ESS3-5 asks that we look at available data for evidence. The webquest assignment will provide students the opportunity to find such evidence.

HS-ESS3-5. Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

The last two standards HS-ETS1-1 and HS-ETS1-3 are engineering design standards that ask students to analyze a global challenge (climate change) and to propose solutions based on prioritized criteria and trade-offs. This is perhaps the most challenging standard as the issues of energy policy as they affect the climate are difficult to address because of the many conflicting priorities. Students must understand that there are no easy answers to our problems given the ramifications of any policy we undertake.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

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