TEAM PROJECT REPORT

Renewable Energy System: A Research Experience and Classroom Implementation Plan

Submitted To

The RET Site
For
"Sustainable Engineering for Urban Needs:
Research Experiences for Middle and High School Teachers"

Sponsored By
The National Science Foundation
Grant ID No.: EEC-0808696

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Reporting Period: June 20 – July 29, 2011

Abstract

Since the industrial revolution, humans have depended primarily on fossil fuels for energy. Abundant availability and low cost of fossil fuels hampered growth of alternative energy technologies. With continued wide-spread use, however, the environmental effects and depleted supply of fossil fuels has renewed interest in finding renewable technologies.

Solar technology is a viable option to replace fossil fuels because energy from the sun is widely available and cost free. Solar technology has existed since the 19th century and has been used to bring energy to remote places. (Wang, 2005) Current solar technologies are not very efficient. A single solar cell can only capture a small fraction of the energy it receives from the sun. (Jiangbin Xia, 2009) (Fanis, 1998) As people transition away from fossil fuels to alternative energy, it is important to understand under which conditions solar cells can create the most energy.

The most common form of solar cell uses silicon to take advantage of the photovoltaic effect and produce electricity. A single molecule of silicon will absorbs light and separates electrical charges at the same time. The silicon in these cells must be highly pure and is expensive to refine. The high price of silicon solar cells has made them cost prohibitive for electricity generation.

Nanocrystalline dye-sensitized solar cells work on a different principle than silicon solar cells. The processes of light absorption and electrical charge separation are themselves separated. Light absorption occurs on a layer of dye attached to a conductive plate coated with a layer of titanium dioxide. Electrical charges are separated by iodine and transferred back to the TiO2 to begin the process again. This new type of solar cell mimics the process of photosynthesis and is much less expensive to produce than traditional silicon solar cells. With increased efficiency, the nanocrystalline solar cell could make a transition to solar energy more feasible. (Fanis, 1998)

This research information in continuing with that from the previous year, with that in mind this acknowledgement needs to be given to Stephanie Baldwin and Deon Edwards, RET participants from 2010 for this abstract.

Goal and Objectives

Research environmental friendly energy alternative which enables energy independence is the goal for this project. In order to achieve the goal small dye-sensitized nanocrystalline solar cells are needed to be assembled using different dyes as well as methods of coating titanium dioxide (TiO_2). Once assembled these cells are then tested by a solar replicator while measuring current and voltage readings.

Research Tasks

Solar technology is a viable option to replace fossil fuels because energy from the sun is widely available and is cost free. The most common form of solar cell uses silicon to take advantage of the photovoltaic effect and produce electricity. Nanocrystalline dye-sensitized solar cells work on a different principle than silicon solar cells. The processes of light absorption and electrical charge separation are themselves separated. Light absorption occurs on a layer of dye attached to a conductive plate coated with a layer of titanium dioxide. Electrical charges are separated by iodine and transferred back to the TiO_2 to begin the process again. This new type of solar cell mimics the process of photosynthesis and is much less expensive to produce than traditional silicon solar cells. With increased efficiency, the nanocrystalline solar cell could make a transition to solar energy more feasible.

A dye-sensitized solar cell is selected for the research. Following tasks are undertaken to assemble and test the performance of this cell:

1. Assemble dye-sensitized solar cell using different dyes.
2. Vary the parameters of interest which may effect the efficiency of the solar cell.
3. Test each type of solar cell assembled.
4. Collect data.
5. Compare data.
6. Recommend the best solar cell.

Methodologies Used

First conventional solar cells were assembled for different types of dyes using the following procedure, which is also illustrated in the photographs included in **Figure 1** on page 3:

1. Clean two conductive glass plates for each solar cell using ethanol to rinse off any contaminates. Use an absorbent tissue paper for drying the plates.

2. Use a multimeter to find which side of the glass plates is conductive. This is required in order to determine which side to apply the coating.

3. The glass plate is then taped to a sheet of copier paper, as shown in the **Figure 1(a)**. The top glass plate is taped down with the conductive side up. The bottom plate is only used to aid in the coating process and is placed with the conductive side taped facing down. The tape is placed such that the strip is no more that 1 to 3 mm wide on the edges of the glass.

4. Using the glass stirring rod, spread a 40 to 50 micron layer of TiO_2 suspension on each plate, as shown in the **Figure 1(b)** and **1(c)**. The thickness of the tape aided in controlling the amount and uniformity of suspension that was being applied. The tape also served as a mask for the areas that do not require coating.

5. The glass plates are carefully removed from the paper. The bottom plate is set aside. The top glass plate is placed on to a baking tile prior to going into the drying oven. The suspension is dried on to the plates in a 450 degree oven heated for 30 minutes. After the drying time is complete the glass plates are allowed to cool down to room temperature.

6. While the TiO_2 coated glass plates are in the drying process, following individual dyes are prepared using the mortar and pestle “juice”: collard greens, raspberries, blueberries, and

blackberries. Synthetic dyes N3 and N719 are also used. Note: Using a juicer will not work due to the separation of liquid and solid pigments.

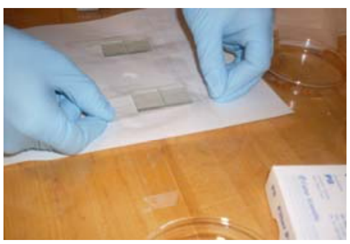
7. The dye is separated from this thick solution using a filtered strainer attached to a Buckner flask. An air compressor/vacuum is also attached to the flask to expedite the separation process. Once enough is created, the natural dye is poured into Petri dishes.

8. The cooled TiO_2 coated plates are inspected for flaws or cracks prior to being placed face down in a selected dye. The Petri dishes containing glass plates with dye are covered with aluminum foil and left to soak overnight, as shown in **Figure 1(d)**.

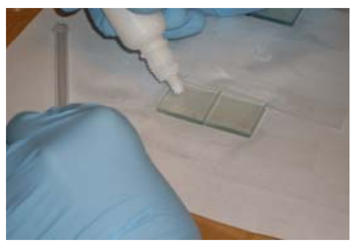
9. A layer of carbon is applied to the conductive side of other glass plates with a graphite pencil, as shown in **Figure 1(e)**.

10. Plates are removed from the dyes, rinsed with distilled water then Ethanol and patted dry.

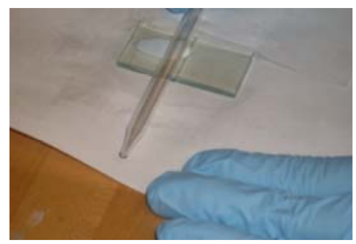
11. Cells were assembled by placing a dyed plate on top of a carbon coated plate in a staggered position. Plates are held together using two small binder clips, as shown in the photograph in **Figure 1(f)**.



(a) Taping the Glass Plate



(b) Applying Titanium Dioxide Solution



(c) Spreading Titanium Dioxide Solution Before it Dries

(d) Dye Titanium Dioxide Side Facing Down

(e) Carbonize the Glass Plate on its Conductive Side Using a Graphite Pencil

(f) Finished Product

(g) Appling Two Drops of Iodine as the Electrolyte

Figure 25. Assembly Process for the Dye-Sensitized Solar Cell

12. One or two drops of iodine are placed along the edge of the combined plates as an electrolyte, as shown in **Figure 1(g)**.

13. Assembled solar cells are ready for testing.

Second, the thickness of the titanium dioxide coating on the glass plates was decreased as follows: After step 3 the glass plate pasted on the paper is put in a spinning device and TiO_2 coating is applied as explained in step 4 above. The device is spun at 1000 RPM for 30 seconds. Then the tape is removed and the plate is baked at the same temperature for same amount of time as in the conventional method, as explained in step 5 above. After doing this, solar cells with different dye coatings (collard greens, raspberries, blueberries, and blackberries, and synthetic dyes N3 and N719) are assembled as explained in steps 7 through 13 above.

Third, similar solar cells as above are assembled using thinner glass plates and spin coating method to apply TiO_2. Using the steps described above, solar cells with different dye coatings (collard greens, raspberries, blueberries, and blackberries, and synthetic dyes N3 and N719) and thinner glass plates are assembled.

Training Received

Training was received for: 1) How to assemble solar cells; and 2) How to make a thin titanium dioxide solution for spray bottle

Research Findings

The results obtained for power from the dye-sensitized solar cell assembled using different dyes, N3 and N719 are shown in **Figure 2**. These results show that the commercial dye N719 produced the most power while blackberry produced the least. These results could be the result of blackberry was the first dye sensitized solar cell produced and the commercial dye N719 was the last. Much practice applying the titanium dioxide occurred between the two dye cells' assembly. The two commercial dyes (N3 and N719) use Ruthenium, but the compound is mirrored in the dyes.

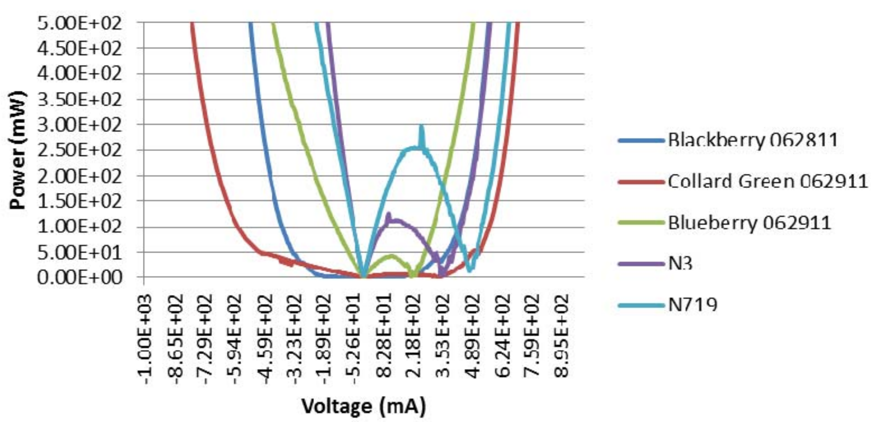


Figure 2. Power Versus Voltage Plot for Cell Assembled Using Conventional Method

The current density was measured by finding the area of the coated cell as a divisor of the current itself. This was used to determine the amount of electrical current or flow was available in the examined cells. The results obtained the dye-sensitized solar cell assembled using different dyes, N3 and N719 are shown in **Figure 3**.

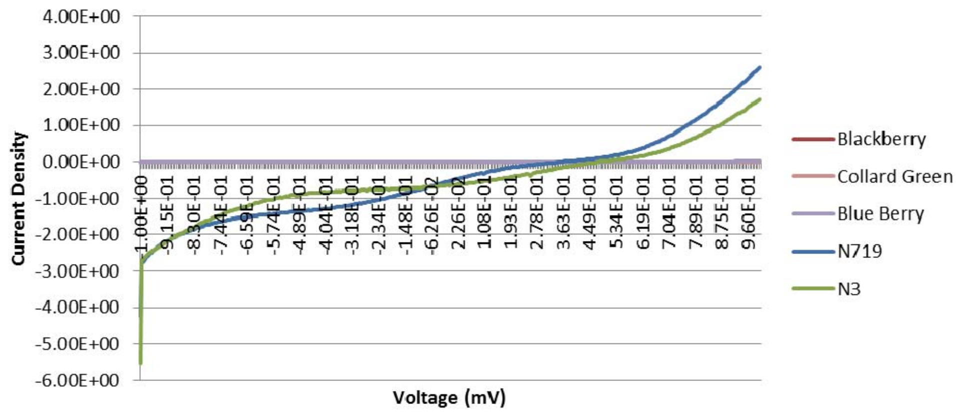


Figure 3. Current Density Versus Voltage Plot for Cell Assembled Using Conventional Method

The graphs in **Figures 4** and **5** on page 7 show the power and current results for the cells assembled using the spin coating method. Interesting things to note is that this is a thinner layer of titanium dioxide which could explain why, as shown in **Figure 4**, the blackberry dye outperformed all other dyes. Also note that the N3 runs along the x-axis - this indicates that the sample short circuited. Further samples of N3 also short circuited using the spin coating method indicating that the binding of N3 and possibly N719, as it underperformed the blackberry, relies on the amount of TiO_2. Comparing the graphs shown in **Figure 5** it can be noticed the change in power as well. Spin coating applies a thinner layer of TiO_2 than that of the conventional method. Concerning the commercial dyes, the power output is halved or short circuit. The organic dyes didn't decrease, but in some cases increased in output. The data collected could be skewed in this manner because more human elements are involved with the conventional method and that could cause initial data collected to be misrepresented.

<u>Classroom Implementation Plan</u>

An interdisciplinary engineering and science lesson is presented on using organic dyes to generate electricity from light. A high school lesson is provided to allow students to explore solar energy and its development as a viable inexhaustible, renewable energy source for the future through the use of dye-sensitized solar cells (DSSC's). The lesson focuses on students developing an understanding, through inquiry and application, of how these cells convert light into energy. Students will measure and calculate DSSC efficiencies under various scenarios and use the cells they build to energize an electrical output device.

Worldwide growth in population, the demand for energy is increasing. In the U.S. alone, the energy demand is increasing at 2.4% annually. Ultimately, our fossil fuel supply will be depleted. We are

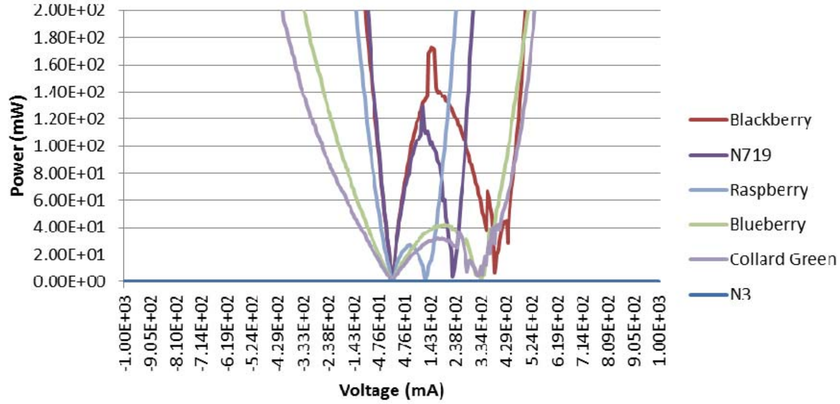


Figure 4. Power Versus Voltage Plot for Cell Assembled Using Spin Coating Method

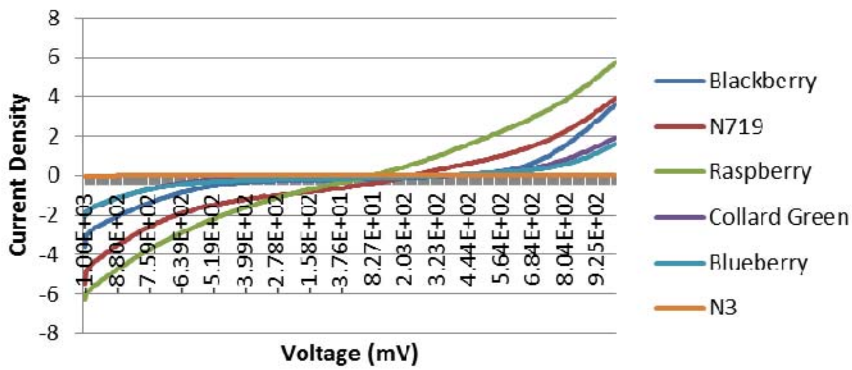


Figure 5. Current Density Versus Voltage Plot for Cell Assembled Using Spin Coating Method

already experiencing the costs associated with supply and demand with regards to our energy needs as well as the other complications that arise. We need an energy source that is in abundance, environmentally safe, economical, renewable, clean, efficient, and accessible to power our consumer needs (i.e., cars, home electrical needs, and electronics). Therefore, engineers are being challenged to find creative ways to generate energy and to make systems more efficient.

Providing a means for students to develop an understanding of how “green” sources of energy are being utilized by engineers and scientists today can provide a pathway for our future engineers and scientists to find creative ways to continue to address the effective energy management needs of our future.

This lesson is designed for students to develop an understanding of the need for sustainable, environmentally friendly energy sources**.** In this lesson students will investigate the solar power research that has taken place thus far (specifically silicon and DSSC solar systems). They will learn through exploration that as energy and power are converted, losses in the system will occur and understand that such losses affect the overall efficiency of the system.

Students will build the dye-sensitized solar cells in class then test and calculate their efficiencies. Then the solar cell can be used to power a small light. Goals are students will understand photovoltaic technology by studying the dye-sensitized solar cell and will build a dye-sensitized solar cell to develop an understanding of how these cells convert light into energy. To objectify these goals students will be able to understand the advantages and disadvantages of solar energy, demonstrate the proper use of a digital multimeter, determine the relationship between voltage, current, and power, build dye-sensitized solar cells using different dyes and explore the effect that different dyes have on voltage and current, build a dye-sensitized solar cell and explore its photovoltaic properties, link dye-sensitized solar cells in series circuits and explore the voltage and current produced, and calculate the efficiencies of the cells under various scenarios.

For schools without an Engineering program, it will be necessary to complete the engineering portion of this project in the Science class. The overall project time line may have to extend to three week in this case. For schools that have students with writing disabilities keep data on an Excel spreadsheet for the group as they build and connect the cell, or they can report observations to a voice recorder. Then have student give a verbal account of what they did, what they observed and what the data means. Assess understanding by encouraging them to apply the new vocabulary they learned in their report

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APPENDIX: LESSON PLANS

Lesson Name: Solar Energy – A Renewable Energy Source

Teachers : Ms. Charlynn Sanford (Engineering)
Mr. Taylor Tootle (Physical Science)

Subject: Interdisciplinary: Engineering & Physical Science
Grade Level: 9th to 12th

Duration: 6 to 8 days

All activities will take place in the Physical Science class. The noted activities are for those schools with engineering programs.

Analyze Learners: Overview and Purpose

Engineering **A**pplication**:** Students will apply the concepts of the dye-sensitized solar cell to a working model..

Engineering **C**areers**:** Careers in nanotechnology are expected to reach 2 million by 2015 and range across many fields; Finance, Marketing and Sales as well as engineering. Engineering career opportunities include Chemical, Biotechnical, Biomedical, and Electrical.

Societal Impact**:** Provision of an energy source that is in abundance, environmentally safe, economical, renewable, clean, efficient, and accessible to power our consumer needs.

Educational Standards Addressed

Overview & Purpose

With worldwide growth in population, the demand for energy is increasing. In the U.S. alone, the energy demand is increasing at 2.4% annually. Ultimately, our fossil fuel supply will be depleted. We are already experiencing the costs associated with supply and demand with regards to our energy needs as well as the other complications that arise. We need an energy source that is in abundance, environmentally safe, economical, renewable, clean, efficient, and accessible to power our consumer needs (i.e. cars, home electrical needs, and electronics). Therefore, engineers are being challenged to find creative ways to generate energy and to make systems more efficient.

Providing a means for students to develop an understanding of how “green” sources of energy are being utilized by engineers and scientists today can provide a pathway for our future engineers and scientists to find creative ways to continue to address the effective energy management needs of our future.

The purpose of this lesson is for students to develop an understanding of the need for sustainable, environmentally friendly energy sources**.** In this lesson students will investigate some the solar power research that has taken place thusfar (specifically silicon and DSSC solar systems). They will learn through exploration that as energy and power are converted, losses in the system will occur and understand that such losses affect the overall efficiency of the system.

Goal

- Students will understand photovoltaic technology by studying the dye-sensitized solar cell (a.k.a. Gratzel Solar Cell).
- Students will build a dye-sensitized solar cell to develop an understanding of how these cells convert light into energy.

Objectives

It is expected that students will be able to;

- Understand the advantages and disadvantages of solar energy.
- Demonstrate the proper use of a digital multimeter.
- Determine the relationship between voltage, current, and power.
- Build dye-sensitized solar cells using different dyes and explore the effect that different dyes have on voltage and current.
- Build a dye-sensitized solar cell and explore its photovoltaic properties.
- Link dye-sensitized solar cells in series circuits and explore the voltage and current produced.
- Calculate the efficiencies of the cells under various scenarios.

Misconceptions

- Solar-powered life requires sacrificing modern conveniences.
- You need storage for solar power.
- Solar power "isn't quite ready for prime time."
- Electricity from solar power is expensive.
- A solar power system requires fossil-fuel energy as a backup.

Assessment

Explanation

- Students will explain the advantages and disadvantages of solar energy.
- Students will explain how a dye-sensitized solar cell works.

Interpretation

- Students will make journal entries reflecting on their learning experiences.
- Students will research dye sensitized solar cells to gain an overall perspective of this technology can conceivably address current energy demands and issues.

Application

- Students will measure and record the DSSC voltage and current output values using a multimeter.
- Students will calculate the power created by their dye-sensitized solar cell.
- Students will calculate the efficiency of their DSSC.
- Student teams will compare their cell's efficiency to silicon and the efficiency of the cells of other teams (using other dyes).

Perspective

- Students will identify and discuss short and long-term global and societal impacts regarding energy.

Self-knowledge

- Students will be required to reflect on their work in journals by recording their thoughts and ideas.

Essential Questions

1. What sources of "green" energy are available for use? What are the benefits and drawbacks regarding efficiency, usefulness, and the environment?
2. What is one of the emerging technologies that is on the horizon that will provide energy more efficiently?
3. What are the different energy sources that are used to deliver energy to your community?
4. Describe solar energy.
5. Describe how the solar cell provides electricity.
6. Describe and identify inefficient use of energy and power at home, school, or work.
7. What is the relationship between power, current, and voltage within an electrical system?
8. What is a dye-sensitized solar cell? Why is it a promising alternative as an alternative energy source?
9. Describe how to calculate the efficiency of a dye-sensitized solar cell.

Vocabulary Terms

Alternative Energy	Any source of energy other than fossil fuels that is used for constructive purposes.
Anode	The positive electrode in an electrolytic cell
Cathode	The negative electrode of an electrolytic cell
Current	The net transfer of electric charge (electron movement along a path) per unit of time.
Electrical Energy	Energy caused by the movement of electrons.

Direct Current	Current that flows in only one direction and has a fairly constant average value.
Dye-sensitized solar cell	A “dye-doped” semiconductor directly converts the energy in light into electrical energy through the process of photovoltaic.
Electricity	The flow of electrical power or charge.
Efficiency	The ratio of the useful energy delivered by a dynamic system to the energy supplied to it.
Electrode	A conductor through which electricity enters or leaves something.
Electrolyte	A chemical compound that separates into ions in a solution or when molten, and is able to conduct electricity
Energy	A fundamental entity of nature that is transferred between parts of a system in the production of physical change within the system and usually regarded as the capacity for doing work.
Inexhaustible Energy	An energy source that will never run out.
Multimeter	Also known as a or VOM (Volt-Ohm meter), is an electronic measuring instrument that combines several measurement functions in one.
Photosynthesis	A process by which green plants and other organisms turn carbon dioxide and water into carbohydrates and oxygen, using light energy trapped by chlorophyll
Photovoltaic	The direct conversion of light into electricity at the atomic level.
Power	A measure of the rate of doing work or transferring energy, usually expressed in terms of wattage or horsepower.
Renewable Energy	A resource that can be replaced when needed.
Resistance	The opposition that a device or material offers to the flow of direct current.
Semiconductor	A solid material that has electrical conductivity between that of a conductor and an insulator
Solar Energy	Radiant light and heat from the sun
Voltage	The potential difference measured in volts. The amount of work to be done to move a charge from one point to another along an electric circuit.
Work	The transfer of energy, measured as the product of the force applied to a body and the distance moved by that body in the direction of the force.

Day-by-Day Plans

Time: Science class - 3 days   Engineering class – 7-8 days

Day 1: (Engineering class)

- The teacher will give a lesson overview explain the Engineering and Science interdisciplinary plan.
- Students, working in groups of 3 or 4, will be given a pretest on the lesson (using the Essential questions) and submit their responses.
- The teacher will have a discussion with students in regards to their answers to the pre-test.

- **Optional:** The teacher may want to distribute the lesson's **Vocabulary Terms Crossword** for homework (students with computers can use the glossary on blackboard, otherwise a vocabulary handout will be provided) once the vocabulary terms have been introduced.

Day 1: (Science class)

- The teacher will introduce and provide background information on the **Nanocrystalline Solar Cells** and present the **Nanocrystalline Solar Cell** power point.
- Students will take notes in their journals.
- The teacher will make up the TiO_2 suspension.

Day 2: (Engineering class)

- The teacher will present the **Energy Sources.ppt**.
- Students will take notes in their journals.

Day 3: (Engineering class)

- The teacher will present to the students a video on "How to use a Multimeter."
- Students (paired) will practice taking voltage and current measurements during the video (**Multimeter Activity**).

Days 2-3: (Science class)

- The teacher will distribute and explain the **Nanocrystalline Solar Cell Activity (**present the **Making a Nanocrystalline Solar Cell** video**).**
- The teacher will assign teams (groups of 4) so that students may begin work on the activity.
- Students will prepare the TiO_2 electrode and dye solution (The teacher will provide blackberries, blueberries, and rasberries as dye options. **Alternatives:** pomegranate seeds or bing cherries).
- Students will soak the TiO_2 in the dye solution and prepare the carbon-coated counter electrode.
- Students will build the solar cell.

Day 4: (Engineering class)

- Students will do research on silicon and nanocrystalline solar cells.
- Students will take notes on their research in their journals.

Days 5-7: (Engineering class)

- The teacher will review the "testing" part of the **Nanocrystalline Solar Cell Activity**.
- Students will complete the **Nanocrystalline Solar Cell Activity** (testing of the solar cell, making tables and graphs, and submitting a final report).
- Students will complete the lesson **Essential Questions** (post test).

Day 8: (Engineering class)

- **Optional:** Students will connect their solar cells to a solar robot and race them 6 inches. Winning team receives certificate and prize.
- Students will complete and submit a reflection report on the lesson.

References:

- Top 5 Misconceptions about Solar Power (http://solar.coolerplanet.com/Articles/top-5-misconceptions-about-solar-power.aspx)

- Nanocrystalline solar cell kit manual