<u>Project # 2</u>: <u>"Renewable Energy System" (Energy Project)</u>

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<u>Faculty Mentor</u>:	Dr. Vesselin Shanov, Associate Professor, Department of Chemical and Materials Engineering, University of Cincinnati.
<u>Graduate Student Mentor</u>:	Mr. Feng Wang, Ph.D. student in Materials Engineering, Department of Chemical and Materials Engineering, University of Cincinnati.

Goals and Objectives

Energy production in an environment friendly way is expected to dominate the efforts of great number of scientists and engineers during the 21^{st} century. The automobile industry is seriously challenged worldwide to adopt the new environmental standards demanding reduced carbon pollution and fuel consumption. Fossil fuel and especially oil use creates uncomfortable geopolitical "energy dependence" for many nations that rely on imported supply.

The State of Ohio with its Third Frontier Fuel Cell Program aims to position Ohio as a national leader in the growing fuel cell industry. In addition, the U.S. Government's call for energy independence is urging the scientific community to come up with alternative energy sources and those in academia to train and prepare the work forces that will practice these technologies in the state of Ohio. The UC CEAS has integrated these realities into the current teaching and research programs giving more emphasis to Renewable Energy Systems.

The <u>major goal</u> of this project was to deliver advanced theoretical and experimental knowledge to the participating teachers in environmentally friendly approaches for power generation, which mainly refers to fuel cell and solar cell technologies. In addition, relevant information on nanotechnology related to energy was provided. In this project a theoretical module of core lectures related to renewable energy technologies were presented followed by an experimental module of four separate experiments that were conducted using the lab facilities described in this section. Each module was taught by the Faculty Mentor in charge with the help of a Graduate Student Mentor.

Equipment, Methods and Experimental Procedures

<u>Hydrogen Fuel Cell</u>: The teachers were trained on the use of the equipment shown in Figure 1. The teachers learnt about the principles of a Proton Exchange Membrane (PEM) hydrogen fuel cell and the experimental techniques to operate it. In addition, they measured, calculated and plotted the current, voltage and energy efficiency of a PEM fuel cell. They also proved experimentally the high efficiency of the PEM fuel cell, and discovered the advantages of the hydrogen technology for power generation that is pollution-free. The teachers will introduce the challenges of hydrogen storage to their students and to some safety issues.

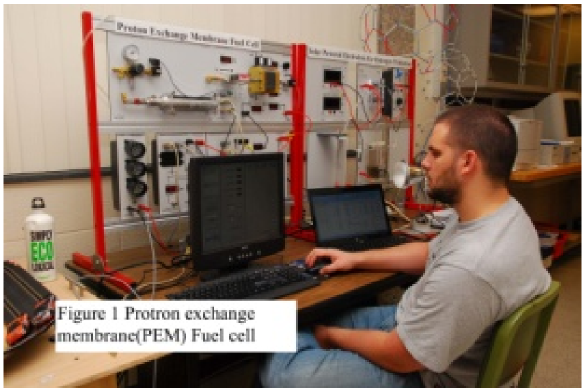
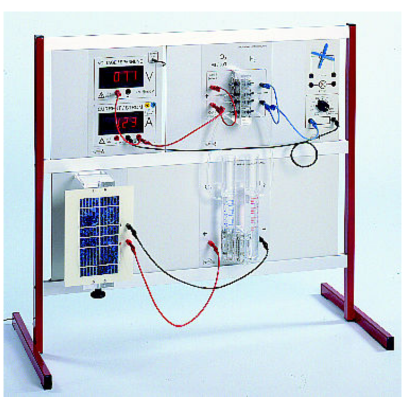


Figure 1. RET Participant Using the Hydrogen Fuel Cell Apparatus

Figure 2. TiO_2 Dye Sensitized Solar Cells

<u>Titanium Oxide (TiO_2) Dye Sensitized Solar Cells</u>: The second experiment the teachers conducted was the construction and testing of TiO_2 dye sensitized solar cells (see Figure 2). In this experiment the teachers built and tested solar cells constructed with inexpensive materials that display promising efficiency rates.

<u>Hydro-Genius Professional System</u>: In the third experiment the teachers used the Hydro-Genius Professional System, shown in Figure 3, which illustrated how the solar energy can be converted into hydrogen by electrolysis of water. This way the sunlight is stored in the form of hydrogen fuel. The electrical power needed to split the water into oxygen and hydrogen in the electrolyzer is provided by a silicon-based photovoltaic cell, which is irradiated with light. The produced oxygen and hydrogen are stored separately and used in a hydrogen fuel cell for power generation. The generated electricity powers a fan and the electrical parameters are registered and recorded.



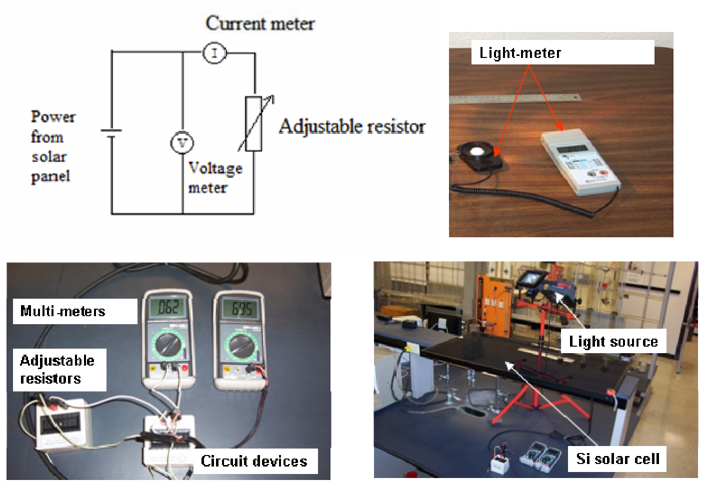


Figure 3. Hydro-Genius System

Figure 4. Photovoltaic Solar Panel Experiment

<u>Photovoltaic Solar Panel</u>: In the fourth experiment the teachers used a commercial photovoltaic solar panel and the instrumentation shown in Figure 4 to characterize the performance of a silicon solar cell.

Testing Efficiency of Fuel Cells Over a Range of Temperatures: The equipment used included - canister of pure hydrogen, fuel cell stack (10), PEM setup, and computer with fuel cell lab software. The step-by-step experimental procedure is:

1. Start the software Instructor 1.2E from the computer.
2. From the selection menu, click the "Experiments > Experiment C.5 (Efficiency of fuel cell stack)" line and then click "Start."
3. Follow the instructions in the "Messages" window. Turn on the fuel cell (FC50) by flipping the switch to the "On" position, then pressing the green "Start" button. It takes some time for the fuel cell to start.
4. Turn on the electric load by flipping the AC power switch behind the panel to the "On" position, and the power switch on the front of the panel to the "On" position.
5. Save the data file in either ".txt" format under the "Experimental Data" window.
6. Click "Start Measuring" button. The operating temperature of the fuel cell stack, for different experiments, needs to be above 40°C. If the temperature is below 40°C, a pop-up screen will appear. To increase the operating temperature, increase the air fan power to 10% by turning the appropriate knob on the computer screen and then increase the load current to 5A by turning the appropriate knob.

The data collection steps were as follows:

1. Set the fan set ting back to "Auto." Start the experiment with initial load current value of 0A. This allows for data collection to begin from 0A load current.
2. To gather a data point, click the "Take Pre-Set Values" button. The clock will start measuring time in seconds. Wait 20 seconds for the hydrogen flow to even out, and then record the current value by hitting the "Store Measurement" button.
3. The current data points are recorded in the right side panel of the window. Note: Occasionally the system automatically purges the H2 out of the system. One can recognize this purging by a clicking sound made by the purging valve (located directly below the air fan).
4. Increase load current value according to the values shown below. Repeat the steps to obtain all data points: 0, 0.2, 0.5, 1, 1.5, 2, 3, 5, 6, 7, 8, 9, and 10.
5. Repeat the data collection for 30ºC, 35ºC, 40ºC, and 45ºC.

Finally, to turn off the equipment the procedure is:

1. Rotate the load current knob counter clockwise completely to zero. Flip the switch on the front panel of the electric load (EL200) to the "Off" position, and the AC switch the back of the panel to the "Off" position. Display will turn off.

2. Flip the switch on the front panel of the fuel cell (FC50) to the "Off" position.

The data was analyzed as follows:

1. Enter the points into Excel.
2. Using recorded voltage and current measurements calculate power, power efficiency, voltage efficiency, current efficiency, and energy efficiency.
3. Using these values create graphs for current vs. each of the other measurements.

TiO_2 Dye Sensitized Solar Cell Experiment: The equipment and supplies needed are glass plates coated with SnO_2 to make it conductive; TiO_2 solution; 3M scotch tape; graphite pencil;

iodine; 3 multi meters; wire and clips; light source; and Lux meter. The step-by-step experimental procedure for construction and testing of TiO_2 cell is:

Step 1: Coat the conductive side of Glass:

1. Grind the nanocrystalline $Ti0_2$ powder in mortar and pestle while adding solvent (nitric or acetic acid solution, pH: 3~4).
2. Use glass rod to spread $Ti0_2$ solution on masked conductive glass.
3. Fire the $Ti0_2$ film at the tip of a flame (450º C) for 15 minutes.

Step 2: Stain the $Ti0_2$ Coating with Natural (Blackberry) Dye:

1. Crush the blackberries in a tablespoon of water.
2. Soak the porous TiO_2 film in this liquid for 5 minutes to stain the coating to a deep red-purple color.
3. Wash the film in ethanol and gently blot it with a tissue until it dries.

Step 3: Coat the Counter Electrode:

1. The positive electrode is called counter electrode and is created from a "conductive" SnO_2 coated glass plate.
2. An Ohm meter can be used to check which side of the glass is conductive.
3. Use a pencil lead to apply a thin graphite (catalytic carbon) layer to the conductive side of plate's surface.

Steps 4 & 5: Add the Electrolyte and Assemble the Cell as follows:

1. Place the stained plate on the table so that the film side faces up.
2. Position the catalyst-coated counter electrode on top of the TiO_2 film plate.
3. Attach two binder clips at the longer plate edges to hold the plates together. Offset the glass plates so that the edges of each plate are exposed.
4. Carefully apply one or two drops of the liquid (iodide/iodine electrolyte solution) at one edge of the plates.
5. Alternately open and close each side of the solar cell by releasing and attaching the binder clips. This action will cause the liquid to be drawn into the space between the electrodes by capillary action and will help to wet the stained TiO_2 film.

Step 6: Test the cell voltage output as follows:

1. Test the open circuit voltage of the cell. Connect volt meter to the cell, the negative lead should be connected to the TiO_2 plate while the positive lead should be connected to the counter electrode.
2. Place Cell under light source.
3. Use lux meter to measure light intensity.
4. Read and record the voltage.

Step 7: Test the power output of the cell the I-V curve as follows:

1. Connect the Cell to one meter to in order to measure current (amps).
2. Connect the second meter to measure voltage.
3. Connect current lead to resistance box set resistance to 500 ohms.
4. Locate the cell under the light source.
5. Using a Lux meter read and record light intensity.

6. Read and record output on both amps and Volts meters.
7. Multiply volts time amps; this equals the power of the cell.
8. Repeat Steps 3-7 10 times increasing the resistance 100 ohms each time.
9. Chart the results.

Highlights of the Research Findings

Fuel Cell Experiment: Both round of experiments showed the same overall results: As the fuel cell the teachers were using approached 45º C the efficiencies and voltage started decreasing faster. This was true for all parameters measured except current efficiency which remained constant over the range of the temperatures tested. This particular fuel cell stack can only tolerate temperatures up to 50ºC and therefore cannot be tested for temperatures above that. This should be considered an area of further research to determine the limits of efficient fuel cell operation.

Ti O_2 Dye Sensitized Solar Cells Experiment: The results of these tests indicated efficiency levels below that of the silicon based panels currently in production. It is believed that efficiency levels will improve with further testing and development. The major attraction of this type of solar cell is the cost of production. TiO_2 Solar cells could be produced at much lower cost than the silicon based cells currently in production. A second round of experiments designed to test the impact of certain lab procedures were conducted looking for a percent increase in efficiency. The factors tested in this second round of experiments were the amount of time and type of furnace used to anneal the Tio_2 film and the length of time the TiO_2 was allow to absorb dye.

Plans for Classroom Implementation

Topics: This work will result in a unit designed to make students aware of the social, and scientific issues that surround energy in the 21st century. Lessons will include science concepts such as the laws of thermodynamics, biogeochemical cycles, trophic Levels, auto cycle engines, electrochemical reactions, and Global warming. Students will also explore the social and economic impact of current energy usage and how changes will impact the world in the future.

Methods: Students will be involved in investigations that will include web quests, direct instruction, as well as hand/minds on experimentation. Students will test the efficiency of both silicon based Solar cells and TiO_2 solar cells they build for themselves. Students will also have the chance to experiment with Hydrogen Fuel cell demonstration cars.

Assessment: The culminating activity will be mock town hall meeting were students, working in groups, will propose and defend a plan for meeting the energy needs of the entire community, including residential, transportation, and industrial energy needs.