Introducing Electrochemical Engineering to Future Generations

by Gerardine G. Botte

One of the challenges that educators and scientists in electrochemical engineering confront is to attract the next generation of researchers and educators in the field. Most of the time, the available engineering problems and outreach programs do not deal with topics of interest in electrochemical engineering. Therefore, new problems and/or demonstrations have to be developed to illustrate the concepts, which requires resources and time. Ideally, demonstrations should be developed that can cover different objectives that can easily be modified or adapted to different audiences.

In this article, different examples of a demonstration of an electrochemical technology that covers different aspects that can be used in the engineering curriculum or as an informal science and engineering program are discussed. The examples shown here can be adapted for other courses and/or outreach programs.

Demonstration

The examples described in this article use the "intelligent fuel cell car lab" demonstration that can be purchased online. The kit costs about $70 (USD) and can be adapted to different applications. A complete experimental description of the system can be found in the catalogues provided with the kit. The examples presented here describe the engineering objectives that were developed around the kit and particularly adapted for chemical engineering freshman courses, and informal science and engineering outreach programs.

Examples in the Engineering Curriculum

The following example has been used successfully in an introductory freshman class for chemical engineering: "ChE-101: Approaches to Chemical Engineering Problem Solving." According to the Ohio University catalogue description[1] the course covers an "introduction to goals and methods of problem-solving techniques; uses of computers for calculations, document preparation. Implementation of selected professional software."

The example shown here (see page 40) is assigned as a course project. The example involves experimentation, data collection, data analysis, development of computer codes and flowchart diagrams, and requires teamwork. The students are split in groups (no more than four members per team) at the beginning of the session (quarter and/or semester). Each team is assigned a car/kit for their project. The students are responsible for scheduling time in the laboratory with the Teaching Assistant assigned to the course in order to collect the experimental data. The students are required to submit progress reports on their projects during the quarter/semester in the form of minutes. Details of the exercise are given below; readers are encouraged to modify the example for other courses. ABET outcomes associated with this project are available upon request.

Examples on Informal Science and Engineering Programs

Different objectives using the same intelligent fuel cell car lab kit have been developed for informal science and engineering outreach programs that had taken place at Ohio University and during different ECS meetings through the Industrial Electrochemistry & Electrochemical Engineering (IE&EE) Division.

Kids on Campus Center for Electrochemical Engineering Research—In this project, students from the Kids-On-Campus program at Ohio University visit the lab to learn about fuel cell technology. This is a local program and uses the methodology presented in this article.

ECS IE&EE Division Outreach program—This program started in fall 2006 and consists of demonstrations presented to high school students on electrochemical technologies. This is an international program and uses the methodology demonstrated in this article.

Engineering Kids' Birthday Parties—This program consists of organizing birthday parties in which the entertainment activities include engineering challenges. This is a local program with the expectation of growing to a Scholars Program. More information about this program can be found in the literature.[2]

In general the first two outreach programs mentioned above include the following:

1. PowerPoint presentation describing fuel cells, sources of hydrogen, energy efficiency, and the guidelines for the competition. The power point presentation is available upon request. This part of the outreach takes about 20 minutes.
2. Preparation for the competition. The students are split in teams (no more than six people per team). Each team works with a mentor. Each team receives a set of instructions for the operation of the car. A complete list of instructions and procedures is available upon request. This part of the program takes 5 to 10 minutes.
3. Data collection and analysis. The students work with their mentors during the data collection. They are also asked to prepare a " team logo" and choose a name for their team. They are also encouraged to come up with a cheering strategy for the team to use during the competition. The students plot the data collected (distance traveled by the car as a function of the hydrogen consumed). The mentors pose questions to the students during this time (*e.g.*, why is there more hydrogen gas than oxygen gas? why aren't all the cars performing the same? what is the effect of roughness?). This part takes 60 minutes.
4. Competition. The students are provided a distance that the car must transverse. The team whose car gets closer to the distance is the winner. This part of the outreach takes 30 minutes.
5. Awards Ceremony. The winners receive a certificate with their names. IE&EE members handle certificates at the end of the competition. This part of the outreach takes 10 minutes.

In general the objectives of this informal science and engineering outreach in electrochemical engineering are: (1.) to introduce the students to the basics of electrochemical technologies, energy efficiency, and fuel cell technology; (2.) to use mathematical tools to analyze data; (3.) strengthen team working strategies; and (4.) describe basics physics and chemistry principles involved in the process. The students have the opportunity to interact with mentors who act as role models.

To date the IE&EE Division had sponsored seven outreach programs with a total participation of 460 students. The program has been facilitated in Spanish and English. The IE&EE donates the "car kits" to the schools for their use in different science

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courses. The teachers of the schools are also encouraged to get in contact with IE&EE members if they want to discuss other applications and/or experiments.

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About the Author

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References

1. Ohio University, undergraduate catalogue 2008-2010, http://www.catalogs.ohio.edu/.
2. G. G. Botte, K. Schneider, and B. Boggs, Kids' Birthday Parties: Having Fun and Learning Engineering, *Proceedings of the ASEE Annual Meeting Pittsburgh*, CD-ROM: AC 2008-1024 (2008).

Course Project: Linear Regression and Plots

As part of your course grade (XX% of the grade), you will get experimental data from an electrochemical system and perform a regression. The electrochemical system that you will work on will be an electro-chem-e-car like the one shown in Fig. 1.

As part of your grade you are required to submit a report to the class. The report should be done using MS Word and it should be no more than six pages (double spaced, 12 font size, 1 inch margin everywhere). The report should include:

1. Title of your project (choose a title for your project). Include the name of all the team members.
2. Theory. This section should briefly describe a proton exchange membrane, an acidic water electrolyzer, and what are the reactions involved (one page maximum).
3. Electrolyzer calibration. You will perform the electrolysis of water. Details about the experimental set-up are given later. Below is described what should be included in the report.
   a. Prepare a graph in MS Excel (follow all the guidelines for quality plot preparation) that shows the volume of hydrogen produced (ml) as a function of time (min) (1 page).
   b. Prepare a graph in MS Excel (follow all the guidelines for quality plot preparation) that shows the volume of oxygen produced (ml) as a function of time (min) (1 page).
   c. Are the volume of the O_2 and H_2 collected the same at any time? If not, please explain (1/4 of a page maximum).

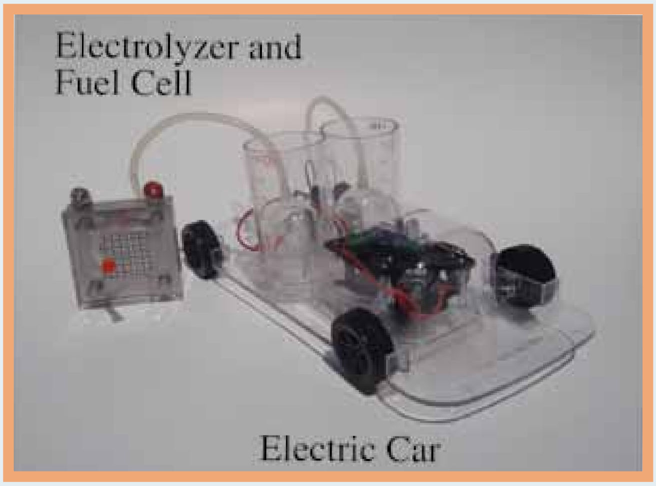

Fig. 1. *An electro-chem-e-car: electrolyzer and fuel cell (left) and electric car (right).*

d. Build a program in MATLAB that will allow you to obtain an equation for the hydrogen produced (ml) as a function of time (min) and for the oxygen produced (ml) as a function of time (min). Your program should be delivered electronically (by e-mail to ______________________, one program for the group). Provide the name of your program in your flowchart diagram.

e. Write the equations for the calibration/regression found using MATLAB (*e.g.*, V oxygen = function(time) and V hydrogen = function(time)) in your report (1/4 of a page maximum).

f. Use the calibration equations to predict how much hydrogen and oxygen will be produced after 1 hour (1/4 of a page maximum).

4. Car calibration. The idea is to calibrate the distance of the car as a function of the fuel used (H_2 volume). The roughness of the floor will affect your results; therefore, have your cars running in the indoor halls of the building. Details about the experimental set-up are given later. Below is described what should be included in the report.

   a. Prepare a graph in MS Excel (follow all the guidelines for quality plot preparation) that shows the running distance (ft) as a function of the hydrogen consumed (ml) (1 page).

   b. Build a program in MATLAB that will allow you to obtain an equation for the distance as a function of the volume of hydrogen consumed. Your program should be delivered electronically (by e-mail to __________________________, one program for the group). Provide the name of your program in your flowchart diagram.

   c. Write the equation for the calibration found using MATLAB (*e.g.*, distance = function (hydrogen volume) in your report (1/4 of a page maximum).

   d. Use the calibration equation to predict the distance for 200 liters of hydrogen. How much volume will be required to travel 300 miles? If this technology was implemented in vehicles, how could the hydrogen be stored? (1/4 of a page maximum).

5. Appendix

   a. Include the flowchart diagrams of your programs in the Appendix.

   b. Include the tables of the data that you measured (that were used to build the plots and to determine the correlations) in the Appendix (see experimental procedures for details about the data to be collected). Make sure that you follow the guidelines for quality table preparation. Make your tables using MS Excel.

Extra credit: On ______________________, we will have a competition among the cars. That day you will be given a distance. You will use your distance/hydrogen calibration equation to know how much hydrogen you will need to produce to run the distance. The team members whose cars stop at the given distance +/-10 inches will receive XXX points extra credit for the XXX grade. The team whose car gets closer to the distance (+/-10 inches) will be the winner and will receive XXX points extra credit.

The car will start with its front end just touching the designated starting point. There will be a designated finish line. The distance will be measured with respect to the front end of the car. The goal of the competition is to have your car stop closest to the specified finish line.

Important: If minutes of the meetings are not submitted according to the tentative schedule, the project will not be graded.

Experimental Procedures

I. Water Electrolysis

1. Materials and supplies

To perform the experiment you will be given:

- Electric car (Fig. 1)
- Electrolyzer/fuel cell (Fig. 2)
- Battery pack (Fig. 3)
- Stop watch (Fig. 3)
- Goggles for eye protection (Fig. 3)
- Bottle with distilled water
- Paper towels
- Cables (2 red and 2 black)
- Beaker
- Syringe

The electrolyzer or fuel cell (also known as the reversible fuel cell because it can work as an electrolyzer or as a fuel cell) is the central device of the car (see Fig. 2 for the parts of the cell, and Fig. 3 for the car with the fuel cell connected). As an electrolyzer electric power is used to break the molecule of water into H_2 and O_2. As a fuel cell, H_2 and O_2 react to produce electricity and water as by-product.

2. Procedure

1. Put on your goggles. Remember safety first!

2. Fill the electrolyzer/fuel cell storage cylinders with distilled water (<u>only</u>). There should not be air space or other gas in the cylinders. To do this follow the procedure described below. (See part numbers labeled as in Fig. 2.)

   a. Place the cell (electrolyzer/fuel cell) on a flat surface. Unplug the gas collectors (3) and gas hoses (2) from the water containers (1).

   b. Use a wash bottle or a small beaker to pour distilled water into the storage cylinders until the water reaches the level typically covered by the gas collectors.

   c. Plug the gas collectors (3) into the water containers (1). Make sure that the bottom is sealed so that gases will not escape.

   d. Connect the gas hoses (2) into the gas collectors (3).

   e. Plug the oxygen gas hose into the fuel cell/electrolyzer.

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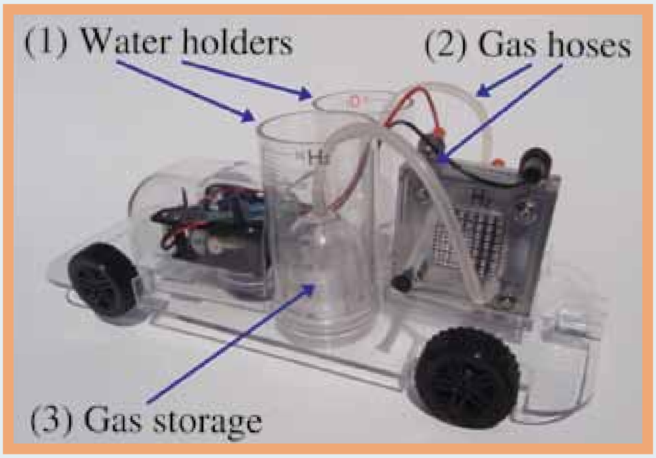

Fig. 2. *Reverse electrolyzer/fuel cell.*

Fig. 3. *(a) Battery pack, (b) stopwatch, and (c) safety goggles.*

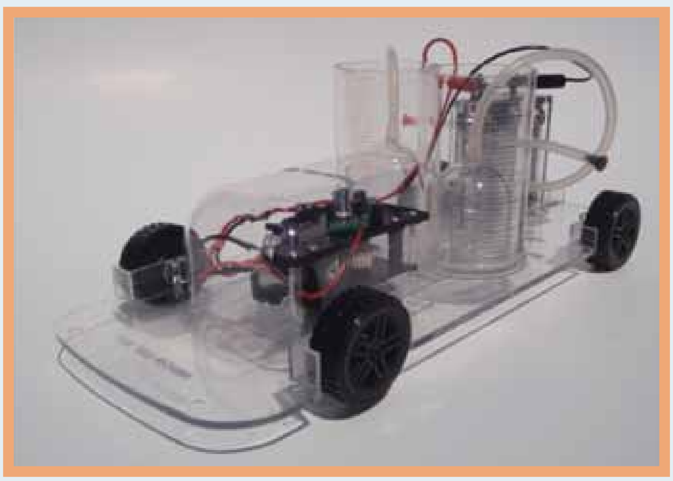

Fig. 4. *The car with the fuel cell connected.*

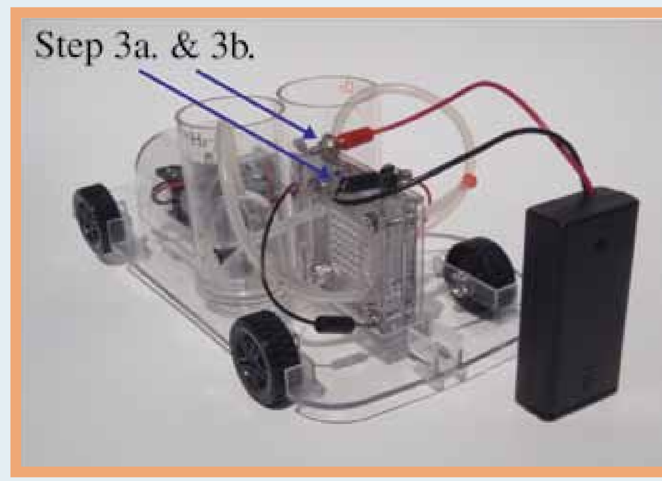

Fig. 5. *Connection of the battery plug to the electrolyzer.*

f. Plug the syringe into the hydrogen side of the fuel cell and vacuum until water from the oxygen water holder comes out from the syringe.
g. Unplug syringe.
h. Plug the hydrogen gas hose into the fuel cell/electrolyzer.
i. Wait 15 minutes before you do the next steps for your first experiment. This will guarantee that the membrane of the fuel cell/electrolyzer will be wet. Dry membranes will significantly affect the performance of the reversible fuel cell.

3. Connect the battery plug to the water electrolyzer (see Fig. 5).
   a. Black wire from the receptacle to black plug on electrolyzer.
   b. Red wire from the receptacle to red plug on electrolyzer.
4. Turn on the battery pack.
5. After Step 4 start measuring your time because your experiment will start. You will see gases coming out the different cylinders (see Fig. 6 for a representation of the situation). As a result your water will get displaced (the gases will take the volume of the water). Fill out a table like this:

Time from start (minutes)	Cathode (black plug) Gas H_2 Volume (ml)	Anode (red plug) Gas O_2 Volume (ml)
0	0	0

6. Once you are finished with the measurements unplug the battery pack from the electrolyzer as shown in Fig. 7.
7. Connect the reversible fuel cell to the motor of the car using the motor cables as shown in Fig.8. Make sure to follow the color code: red cable to the red plug and black cable to the black plug. Let your car run until all your gases are consumed (water will start filling the space where the gases were stored).
8. Repeat your experiment at least 3 times and use the average volume and the average times for your computations. That is the volumes that you will use for the calibration (and plots) will be the average of the volumes collected (for oxygen and hydrogen), and the time will be the average of the times measured.

II. Car Calibration

1. Materials and supplies

To perform the experiment you will be given:

- Goggles for eye protection
- Electric car
- Electrolyzer/fuel cell
- Battery pack
- Bottle with distilled water
- Ruler or measurement tape
- Paper towels
- Cables (2 red and 2 black)
- Beaker

2. Procedure

1. Put on your goggles. Remember safety first!
2. Produce a determined amount of hydrogen in your electrolyzer. To do this follow Steps 2-6 from the electrolysis experiment.
3. Connect the reversible fuel cell to the car electric motor as described in Step 7 of the electrolysis experiment (See Fig. 8). Let your car run until all your gases are consumed (water will start filling the space where the gases were stored).
4. Record the distance at which the car stops.
5. Fill out a table like this:

Volume of H_2 (ml)	Distance transversed (ft)
0	0

6. Repeat your experiment at least 3 times for each volume of H_2. Use the average distance to make your graphs and to obtain the calibration equation.

III. Protocol

You will perform the experiments in lab ______________ of the ___________________ building. You need to leave the lab organized and clean after the experiments. Be sure to arrange working times with the Teaching Assistant(s) of the class (______________________________), so that they can give you access to the equipment needed. Once you are done with your experiment, let the Teaching Assistant(s) know so that she or he can come into the lab and give you the okay to leave (that is, everything should be cleaned and organized, and all parts must be returned).

Enjoy your experiments! This is an example of what chemical engineers do!

Fig. 6. *Example of gas generation in the PEM electrolyzer.*

Fig. 7. *Schematic of the battery pack unplugged from the electrolyzer.*

Fig. 8. *Connection of the fuel cell to the electric motor.*