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Implementing Graphene and Graphene Oxide in a Proton Exchange Membrane Fuel Cell

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IMPLEMENTING GRAPHENE AND GRAPHENE OXIDE IN A PROTON EXCHANGE MEMBRANE FUEL CELL

Abstract

Proton Exchange Membrane Fuel Cells (PEMFCs) are efficient energy systems, which convert hydrogen and oxygen from air into clean water and generate combined heat and electric energy. Despite PEMFCs economically produce environmentally friendly energy however their main disadvantage is their expensive manufacturing cost since they use precious metal like platinum as catalyst for both anode and cathode electrodes. Graphene and graphene oxide could function more efficiently than the platinum catalyst. Graphene and graphene oxide are well known with their high electric conductivity, Graphene Oxide could potentially take the place of platinum as the main catalyst used in PEMFCs. Moreover, the cost of graphene oxide is comparatively much cheaper than platinum and therefore it holds great promise to enhance the commercialization and market share of PEMFCs as cost effective power source.

Keywords—Proton exchange membrane, Fuel Cell, Nafion, Platinum Catalyst, Graphene, Graphene oxide

INTRODUCTION

A Fuel cell is mainly involved the use of hydrogen and oxygen which together combine to form water and energy in the presence of a catalyst. The main advantages of using fuel cells is its high efficiency of operation and does not produce carbon dioxide as an end product. Carbon dioxide is the main cause of the greenhouse effect and climate changes. Thus fuel cell is ideal for energy production but its major drawback is the high manufacturing cost of the catalyst from platinum as a precious metal.

In a typical PEMFC, hydrogen is fed at the anode and oxygen with the atmospheric air is fed to the cathode as platinum is chosen to be the catalyst at both electrodes. The membrane is made of Nafion. Due to the affinity of hydrogen to oxygen electrons are separated from the hydrogen atom assisted by the catalyst to form ions or protons. The protons travel through the membrane and reach the cathode where it combines again with electrons forming hydrogen which reacts with oxygen to form water, which is the byproduct of this process. The electrons travel in an external circuit to create the electrical energy. The main advantages of using PEMFC is that it is easy to operate, and it is easy to install. Disadvantages of using PEMFC include its high manufacturing cost and the difficulty in handling hydrogen when it is in its purest form. Also, the end-product is water, making it eco-friendly which accounts for low maintenance [1]. Moreover, it involves the usage of precious metals like platinum, which accounts for its high cost. In the present, graphene and graphene oxide were used in a fuel cell and were found to replace platinum catalyst. The cost of graphene oxide is comparatively cheaper than platinum. However, more importantly for the applied research work, all the data collected was done within applied learning and highly dynamic learning environment. This type of applied learning comes with many benefits in comparison to traditional learning in a classroom setting. One of the main benefits is that the student can immediately learn by physically doing and then see the impact of a scientific or engineering theory on a subject in a real-world application. Furthermore, the experiments were designed to give the students a sense of what it would be like to work as a professional and prepare them for post-graduation career opportunities. Giving the students such hands-on experience proved to be invaluable because this type of applied learning through research and discovery is very similar to how the industry operates on a daily basis in the research and development environment.

Components of a Fuel Cell

PEMFC usually consists of a Membrane Electrode Assembly (MEA) and hardware parts which includes bipolar plates and gaskets. As shown in Fig1, the membrane electrode assembly consists of a membrane, catalytic layers, and gas diffusion layers.

1. Membrane: The membrane is the one that allows only protons to pass through it and prevents the passing of other ions. It is generally a very thin layer [1]. It only allows protons and blocks the rest of any other types of ions.

2. Catalytic layers: A layer of catalyst is applied on both anode and cathode electrodes. It is usually in the form of a paste. It is a combination of carbon, Nafion liquid and the catalyst, which is platinum [1]. On the anode side, hydrogen is split into protons and electrons by the platinum catalyst.

3. Gas diffusion layers (GDL): It is mainly used to transport the reactants to the catalyst and enables removal of water which is the end product. The gases can easily pass through the pores in the GDL.

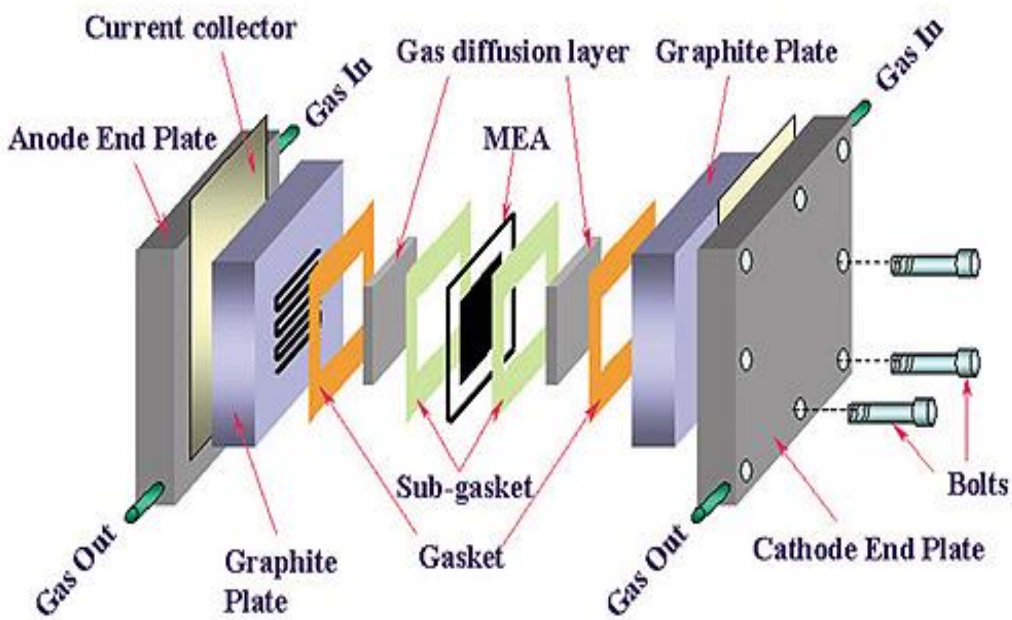

Fig 1: Various components in a fuel cell

How PEMFC works?

From Fig2, we identify that the two most essential and expensive parts of a PEMFC are the platinum catalyst and the Membrane Exchange Assembly, (Holton and Stevenson, 2013). The Membrane is normally made from Nafion, a copolymer of tetrafluoroethylene (Teflon®) and perfluoro-3,6-dioxa-4-methyl-7-octene-sulfonic acid (Nafion, 2017) [2]. Platinum is an extremely expensive material (928.65/oz) (Platinum Prices, 2015), but Platinum works extremely well with Nafion due to their mutual relationship. Platinum allows for the high transfer of protons across the membrane and the rapid exchange of hydrogen molecules to ions.

Graphene Oxide Nanosheet was tested as a proton conductor to determine whether the material has a high value of proton conductivity [2]. From Fig3, Graphene Oxide was able to transport protons, because of its high stability and it's closely located oxygenated functional groups (-O-, -OH, and -COOH) that propagate outwards and can form into channels for proton transport [3]. Graphene Oxide could function as the membrane electrode assembly in a PEMFC. With a high ionic conductivity, Graphene Oxide could potentially take the place of Nafion as the main membrane used in PEMFCs [4].

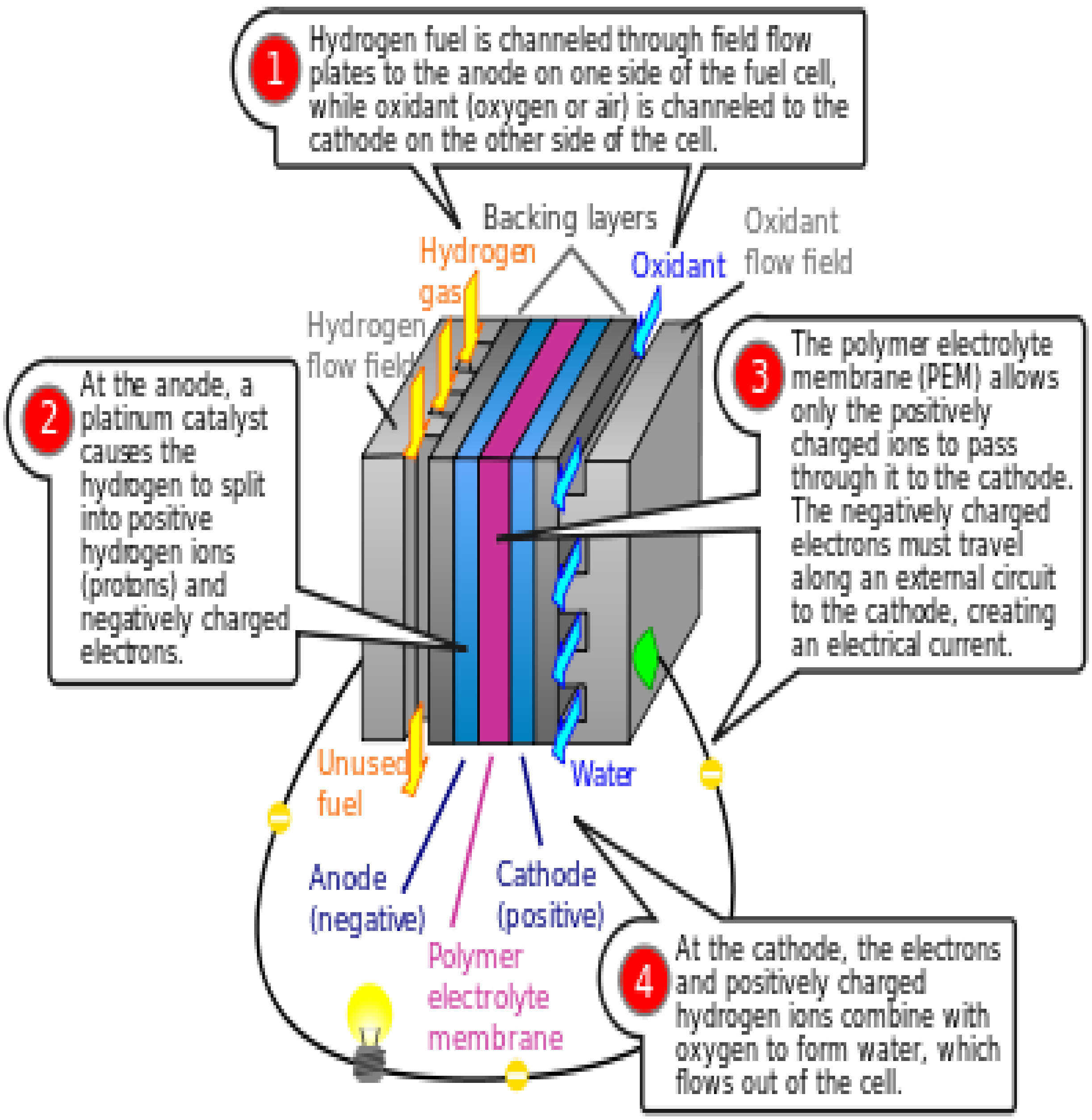

Fig 2. Working of a fuel cell

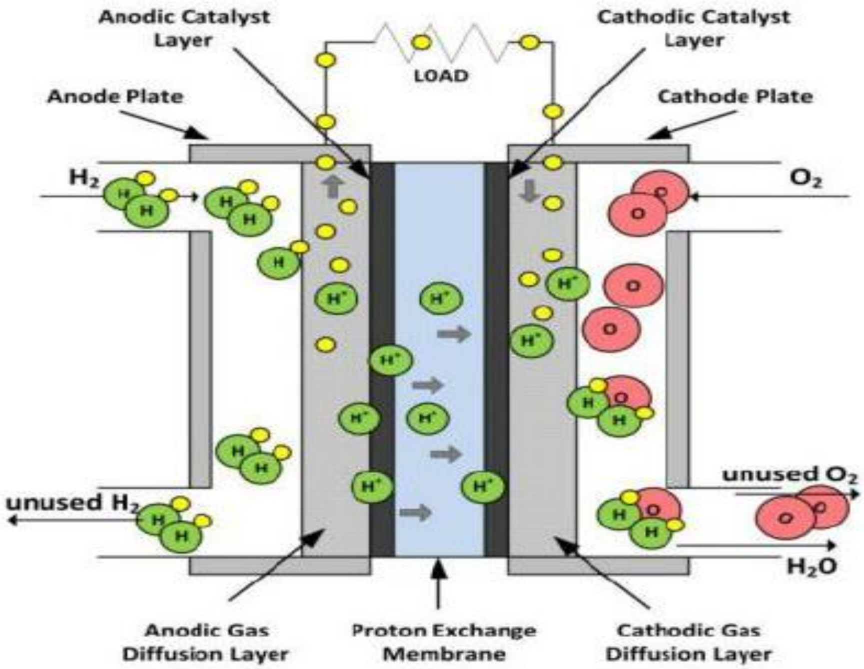

Fig 3: Schematic representation of movement of ions in a fuel cell

Graphene and Graphene Oxide were predicted to provide a positive change in the efficiency of Proton Exchange Membrane Fuel Cells. If Graphene and Graphene Oxide are introduced to a PEM Fuel Cell as the Membrane Electrode Assembly and compare these new implications to Nafion, the Fuel Cell standard, then Graphene Oxide will be a more efficient proton conductor than Nafion and Graphene, based upon its favorable chemical characteristics. Using the DC Load Monitor, a polarization curve was calculated by implementing various currents and measuring the voltage. Using this data, it could be determined to see whether the variables had a positive or negative effect.

As shown in Fig4, Fuel Cell Car Science Education Kit by Horizon Educational was used as the model fuel cell. All steps were followed accordingly and finished when the cell was connected to the DC Load Monitor, the machine that was used to test to the polarization curve. First tubes were needed to be cut that was given so there were 4 total tubes being 4 cm. Next AA batteries (1.5 V) were inserted into the battery case, which provided the power in the electrolysis experiment.

Then, two tubes were connected to the lower nozzles of the hydrogen fuel cell, each on the hydrogen and oxygen side. Then distilled, polarized water was placed into the fuel cell through the oxygen side using a syringe to put the water in through one of the tubes. After this was complete, caps were put on each tube to make sure no water could leak out. Then, there are two glass cups that acted as the hydrogen and oxygen containers. Each of these cups had water filled up to the 0 line, which is about halfway up the cup. Then, the domes were placed with the point facing up into the cups. Water was removed due to water displacement. The other two tubes were then connected to the tip of the dome and the other nozzles on the fuel cell, acting as a tube to transport the hydrogen and oxygen when produced. Now, the AA battery (1.5 volts) provided power to the machine in electrolysis, allowing for the fuel cell to produce hydrogen and oxygen from water and energy. After this was complete, the fuel cell was connected to the DC Load Monitor and the polarization curve was calculated by graphing voltage vs current.

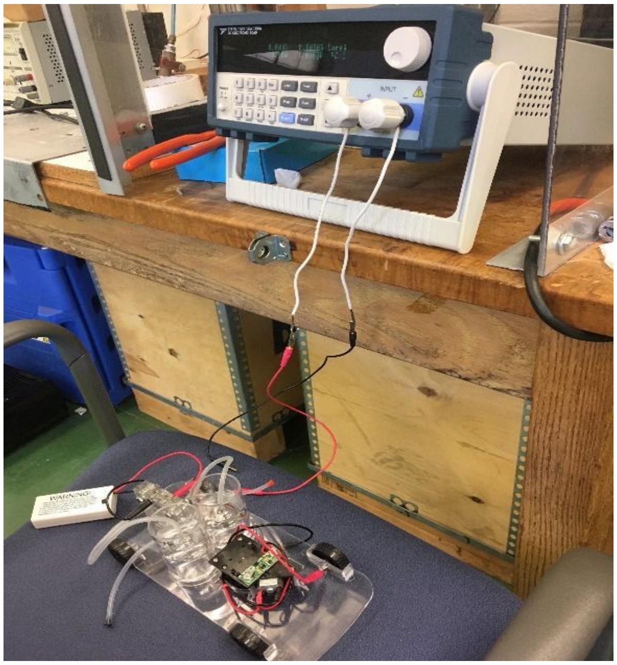

Fig 4: Fuel cell connected to DC load monitor

Connecting the Fuel Cell to the DC load monitor

Multiple Proton Exchange Membrane Fuel Cells were utilized and manipulated. The *Fuel Cell Car Science Education Kit* provided a fuel cell that was used in the experiment. The independent variable was the proton exchange membrane. The cell that acted as the control was purely Nafion with a platinum catalyst. This cell was connected to the DC Load Monitor.

Inside a ball miller, researchers broke graphite down into single-layer graphene nanoparticles, while the canister turned, they injected chlorine, bromine or iodine gas to produce different catalysts. In each case, the bond strength between two oxygen atoms weakened. The weaker the oxygen bonds become, the more efficiently oxygen was reduced and converted to water. The graphene particles were then sanded down into a fine powder and placed into the cell after 5 mg of powder was produced. This powder was then added to the cell and the cell was put back together. For the Graphene Oxide, a different procedure was taken due to the Graphene Oxide being bought as an aqueous solution. A syringe was used to inject the Graphene Oxide into the Nafion Membrane in this manner [5]. Polarization curves were plotted for control, graphene and graphene oxide separately.

Observations

1 NAFION

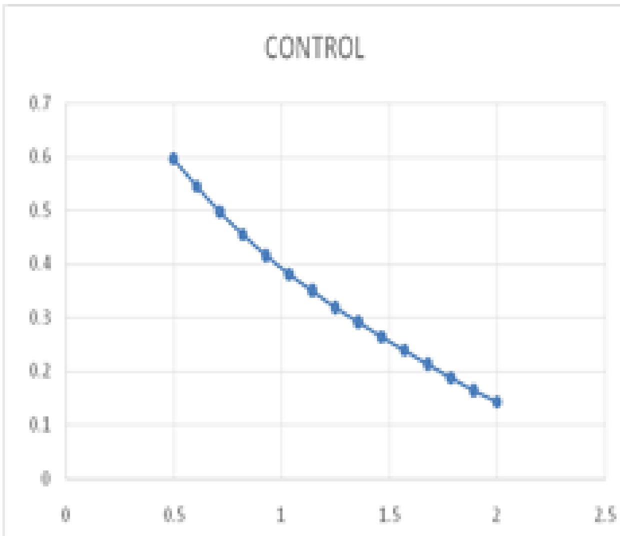

Fig 5: Polarization Curve of the control PEMFC, analyzing current (amps) by voltage (volts).

2 GRAPHENE OXIDE

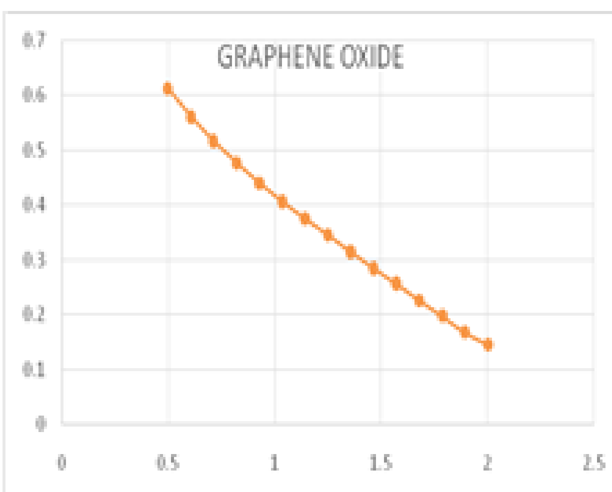

Fig 6: Polarization Curve of Graphene Oxide Cell, analyzing current (amps) by voltage (volts).

3. GRAPHENE

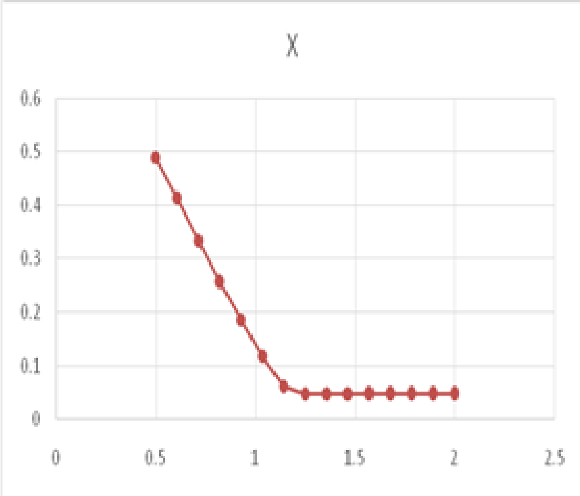

Fig 7: Polarization Curve of the Graphene Cell tested, analyzing current (amps) by voltage (volts).

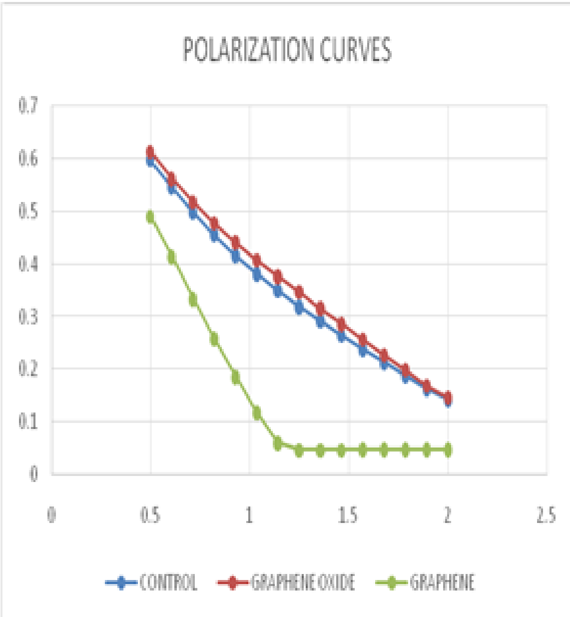

Fig 8: All the Polarization Curves placed onto one graph, where power provided is determined by the area under each of the curve

Fig 5 denotes the polarization curve of the control which consists of the platinum catalyst. Later, graphene and graphene oxide were utilized to replace platinum catalyst and corresponding polarization curves were plotted as shown in Fig 6 and Fig 7 respectively. All the three curves were plotted on a single graph as shown in Fig 8 indicating that graphene oxide proves to perform best.

Cost Analysis

The important reason for PEMFC not being used widely is their cost. So, it is not economical to use these as a source of energy replacing fossil fuels. The power for each is calculated by taking the area under each graph. From the graphs, we find that the power of each cell.

Power of control = 0.5150 watts
Power of graphene = 0.3560 watts
Power of graphene oxide = 0.5450 watts

The cost of each of the component according to standard cost in the US was found to be,
Nafion membrane - $180/gram
Graphene - $120/gram
Graphene oxide - $125/gram

The ratio of power/cost was determined for each cell and are as follows:
Control - 0.002861
Graphene - 0.002967
Graphene oxide -0.004360

From the above analysis implementing graphene oxide to the fuel cell makes it more efficient.

Impact in Engineering Technology Education

Emerging technologies such as those involving alternate forms of energy are expected to play a major role in modern engineering technology curricula. The results presented in this paper involve expertise from multidisciplinary teams in our school of engineering technology; in particular, technology of fuel cell, control systems, fluid mechanics, thermodynamics, and software applications. Major parts of this work were performed as student projects in the school of engineering technology. Namely the student was involved in setting up the fuel cell system, developing code for control algorithm and data acquisition, and running the experiments at Farmingdale State College supported by the Department of Energy (DOE). It is expected that this lab setup will be used in future undergraduate senior projects for students in the departments of mechanical engineering technology. In addition, interdisciplinary courses in alternate forms of energy, fuel cell, solar energy systems, and control mechanisms could be developed in the future as outgrowth of these experimental setups and activities. Parts of the algorithms developed have also been used as examples in existing courses.

In this paper we analyzed the optimal performance of Proton Exchange Membrane Fuel Cells (PEMFCs) which function by converting hydrogen into water and energy. With a high ionic conductivity, Graphene Oxide is found to be more effective than Nafion as the main membrane used in PEMFCs.

The performance of the fuel cell system is influenced by many different parameters. Temperature is an important parameter to the maximize power. We will continuously investigate the relationship between temperature, humidity, time and power. For real life applications, we need to develop a more sophisticated system to consider many parameters in the extended running of fuel cell system.

Conclusions

1. Testing the cathode coated with iodine etched nanoplatelets, performed the best. It generated 33% more current than a commercial cathode coated with platinum. Electrodes coated with nanoplatelets maintained 85.6-87.4% of initial current, while platinum electrodes maintained only 62.5%.

2. CO was added to replicate the poisoning that many scientists blame for the poor performance of platinum [6-8]. The performance of graphene-based catalyst was unaffected.

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