FINAL TECHNICAL REPORT

Feasibility Study of a Fuel Cell Technology in Automobile Application

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16. Abstract

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In order to understand the basics of fuel cell, mini fuel cell kit has been tested in different concentration and different number of cells. We tested the outputs in voltage and current from varying numbers and different volumes of methanol and sodium hydroxide. It was found that very large numbers of cells were required to produce reasonably large voltages and currents. Secondly, solar power fuel cell system that generated hydrogen through solar system and supplied it to the fuel cell system directly was tested under different conditions. Thirdly, a prototype power wheel car system PEM fuel cell is designed. A six (6) Volt and three (3) Amperage Proton Exchange Membrane (PEM) Fuel Cell System was tested on a prototype model. It is concluded that PEM fuel cells can be used in an automobile application. However, there are some barriers for mass production of a fuel cell powered car that need to be overcame such as cost reduction and further development of components of the system.

Prototype II has been built to maximize the power usage PEM Fuel Cell could generate. Comparison analysis of fuel cell usage was performed between two different rated motors. It is believed that the better rated the motor is, the higher performance the fuel cell and motor system generates.
Mini prototype car system was designed and built for feasibility study of fuel cell vehicle. The cost issue of direct hydrogen fuel cell vehicle was discussed.

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The mini prototype car system was designed and built to study the feasibility of fuel cell vehicles and the cost issue of direct hydrogen fuel cell vehicle was discussed.

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SECTION 1

1.1 Introduction

In recent years, there have been rapid increases in the density of motor vehicles on our nation's transportation routes. The vast majority of these vehicles use traditional fuels such as gasoline. These fuels completely burn in oxygen, and they release carbon dioxide into the atmosphere, because they are organic compounds. In cases where incomplete combustion occurs, the toxic gas carbon monoxide is produced. This deadly compound is responsible for many deaths as it binds to hemoglobin approximately 400 times more readily than does oxygen [1]. Traditional fuels are also responsible for a commensurate increase in atmospheric pollutants such as ozone and smog. Not only are these pollutants the cause of health related problems in humans, but also result in significant environmental damage such as acid rain, smog, and ozone depletion. A significant portion of all pollutants in the air comes from automobile exhaust systems [2]. Also, the world's energy supply is depleting. There is a need to find alternative energy sources on earth. As a result of all the problems associated with organic fuels and the scarceness of energy sources, several research projects, including this one, are currently exploring the possibility of using fuel cells instead of traditional fuels [3].

Fuel cells provide a clean source of energy without combustion. Fuel cells are devices that generate electrical power from a chemical reaction without moving parts and virtually without pollution. They convert the chemical energy of the fuel directly into usable electricity. Its chemical energy derives from a continuous flow of fuel and air, which feeds into electricity producing chemical reaction [4]. Unlike batteries, their fuel replenishes indefinitely. Hydrogen fuel cells are the most common variety. They combine hydrogen and oxygen in the presence of a catalyst to form water, releasing energy in the process. The use of hydrogen, which is essentially inexhaustible, and the fact that these cells produce water as a byproduct, instead of carbon dioxide and other pollutants, make them very attractive as a future energy source, especially in automobiles [5].

The assembly of a fuel cell is done in a box-shaped stack. Oxygen and hydrogen are brought to wet membranes to react and generate water. Surplus water should be taken out along with generated heat. To avoid overheating and membrane damage, the cells are arranged in a series, and the voltage adds up while the same current flows through the entire stack. Hydrogen and oxygen flow in manifolds, typically building off the side of the stack, and are divided into parallel feeds into the individual cells [6]. Water and exhaust gas are collected in another manifold and are rejected into the atmosphere. Each fuel cell contains MEA (membrane electrode assembly), which is a polymer ion-conduction membrane with flat electrode sheets attached to either side. Oxygen and hydrogen are channeled to the cathode and anode sides, respectively, in flow fields. The membrane must pass hydrogen through ions but not electricity; the plates must conduct electricity but not allow water, hydrogen, or oxygen to permeate. Separator plates are used to resist the corrosion caused by the electrochemical potentials in the cells. They are made from graphite, which has low electric conductivity.

The objectives of this project are to, conduct a literature survey of the fuel cells that are to be used in an automobile application, to design a prototype, and to test and demonstrate a fuel cell system in an automobile application. The feasibility of a fuel cell automobile application system will be researched, and the cost of the system will be calculated. Fuel cells are to be explored to understand the basics of the fuel cell systems. The appropriate fuel cell and its supplier, along with the car, will be identified for the prototype and tests will be conducted to find out power, velocity, force, and work of the system to show the application's feasibility.

SECTION 2

2.1 Literature Survey

In order to understand the fuel cell characteristics and the research status, a literature search was conducted extensively, including the design and applications over the Internet, and a collection of reviewed books, articles, and research papers in professional journals. In addition to the web pages of the Department of Energy, the Department of Transportation and certain universities, such as Virginia Tech, some of the commercial companies that are researching fuel cell design and fuel cell applications were surveyed. Most of the technical papers that were found discussed the difficulties in applications and cost issues related to building a prototype and barriers to commercialize some of those prototypes.

Energy Partners [7], H Power [8], Warsitz Enterprise [9], DOE [10], Desert Research Institute [11], and Ballard Co. [12] are some of the industry sources that were explored. The Fuel Cell Handbook [13] has been acquired to understand the fundamentals of the system and the reactions taking place in the system. Theoretical parts of the project and applications were extracted from the handbook and incorporated with other publications.

Research completed by Bruce Lin at Princeton University [14] gave some guidance and information about general fuel cell study in replacing combustion engines with fuel cell. The thesis research was an extensive work on a scooter application of a Proton Exchange Fuel Cell. A fuel cell design, scooter performances, and pollution trends were examined along with the requirements, and a prototype design was presented. It concluded that advanced fuel cell powered scooters could produce more than three times the 100 mpg of current gasoline-powered scooters, with zero tailpipe pollution. Today the consumer price of a fuel cell powered scooter is higher than a combustion engine scooter. However, the price of the fuel cell powered scooter is expected to be reduced by half in the future.

2.1.a   Fuel Cell Fabrication

A PEM (proton exchange membrane) fuel cell is made of two plates sandwiched together with a plastic membrane coated with a catalyst. A schematic diagram of an individual fuel cell system is shown in Figure 1.

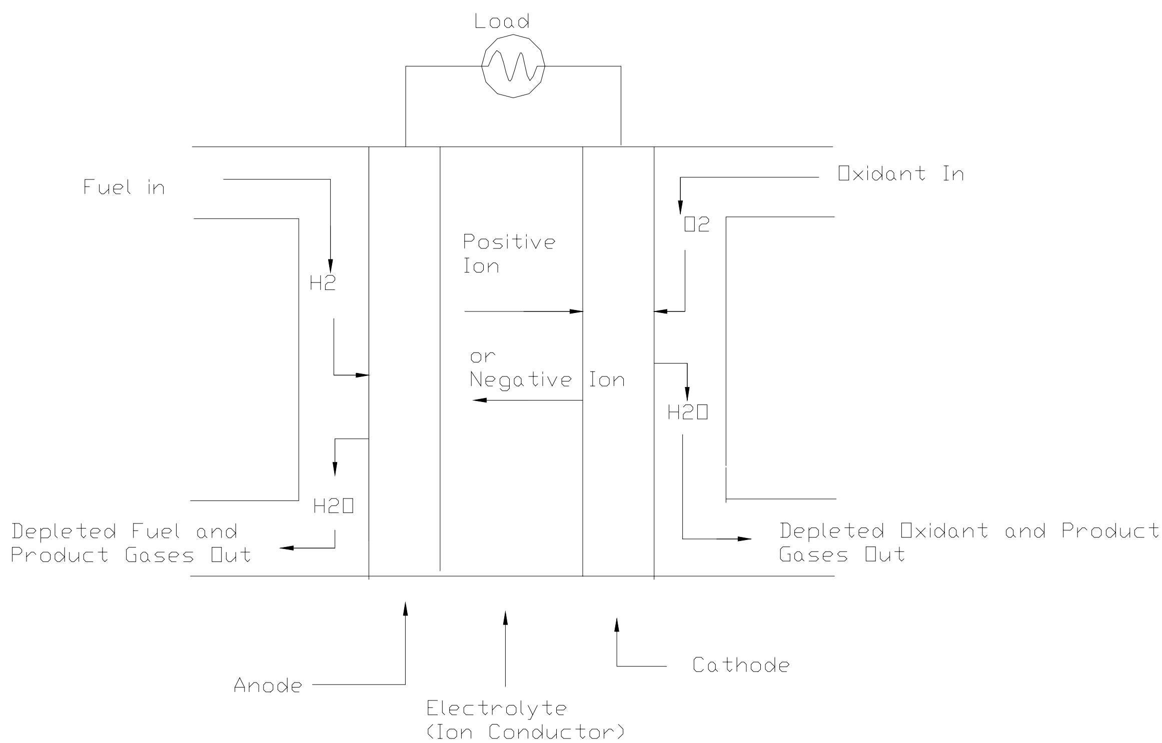


Figure 1 Schematic Diagram of an Individual Fuel Cell

Hydrogen from methanol, natural gas, or petroleum and oxygen from air are fed through channels in the plates. Hydrogen is on one side; oxygen is on the other. The hydrogen and oxygen want to be together. The shortest way is through the membrane, but only part of the hydrogen atom, the proton, can pass through the membrane. The other part, the electron, has to take the long way around through an external circuit, creating useful electricity. The oxygen side attracts the protons and the electrons that have traveled through the external circuit generating the byproducts of water and heat. A single fuel cell consists of a membrane electrode assembly and two flow field plates.

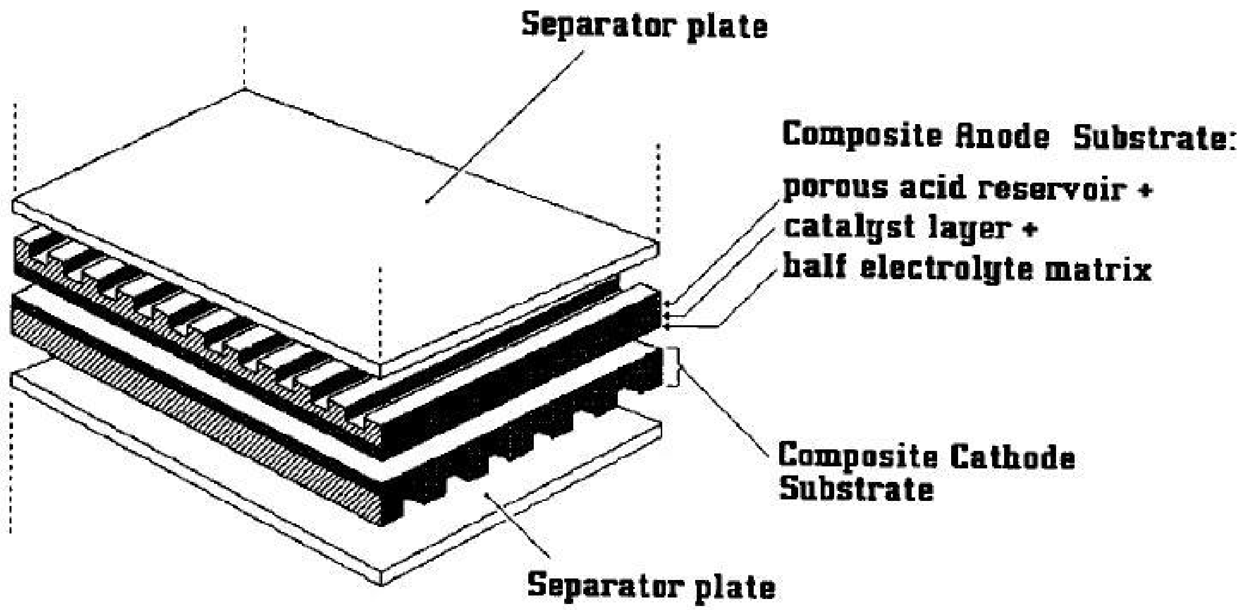


Figure 2 Expanded View of a Basic Fuel Cell Repeated Unit in a Fuel Cell Stack

Single cells are combined into a fuel cell stack to produce the desired level of electrical power. Figure 2 shows a schematic diagram of the fuel cell stack put together to generate higher voltage. Gases (hydrogen and air) are supplied to the electrodes on either side of the PEM through channels formed in the flow field plates. Hydrogen flows through the channels to the anode where the platinum catalyst promotes its separation into protons and electrons. On the opposite side of the PEM, air flows through the channels to the cathode where oxygen in the air attracts the hydrogen protons through the PEM. The electrons are captured as useful electricity through an external circuit and combine with the protons and oxygen to produce water vapor on the cathode side.

A fuel cell will operate continuously as long as hydrogen is supplied. By combining single cells, large fuel cell stacks can be manufactured to produce the required amount of power.

A fuel cell system consists of a fuel processor, air supply subsystem, cooling subsystem and controls. Combining these subsystems with the fuel cell creates a fuel cell engine, which can power a car, truck, bus or other vehicle [15].

The electrochemical reactions of the PEMFC (Proton Exchange Membrane Fuel Cell): hydrogen at the anode provides a proton, freeing an electron in the process that must pass through an external circuit to reach the cathode. The proton, which remains solvated with a certain number of water molecules, diffuses through the membrane to the cathode to react with oxygen and the returning electron. Water is subsequently produced at the cathode.

Anode: $2H_2$ ----------> $4H^+ + 4e^-$

Cathode: $4e^- + 4H^+ + O_2$ ----------> $2H_2O$

Overall: $2H_2 + O_2$ ----------> $2H_2O$

Because of the intrinsic nature of the materials used, a low temperature operation of approximately 80^0C is possible. The cell is also able to sustain operation at very high current densities. These attributes lead to a fast start capability and the ability to make a compact and lightweight cell. Other beneficial attributes of the cell include lower sensitivity to orientation and no corrosive fluid hazard. As a result, the PEMFC is particularly suited for vehicular power application. Transportation applications mean that the fuel of choice will probably be methanol, although hydrogen storage on-board in the form of pressurized gas and the partial oxidation of gasoline is being considered. The cell is also being considered for stationary power application, which will use natural gas or other hydrogen-rich gases. The lower operating temperature of a PEMFC results in both advantages and disadvantages. Low temperature operation is advantageous because the cell can start from ambient conditions quickly, especially when pure hydrogen fuel is available. The disadvantage is that platinum catalysts are required to promote the electrochemical reaction. Carbon monoxide (CO) binds strongly to platinum sites at temperatures below 150^0C, which reduces the sites available for hydrogen chemisorption and electro-oxidation. Because of CO poisoning of the anode, only a few parts per million (ppm) of CO can be tolerated with the platinum catalysis at 80^0C. Because reformed hydrocarbons contain about one percent of CO, a mechanism to reduce the level of CO in the fuel gas is needed. The low temperature of operation also means that little, if any, heat is available from the fuel cell for any endothermic reforming process. Both temperature and pressure have a significant influence on cell performance. Present cells operate at 80^0C, nominally, 0.285 Mpa (30 psig), and a range of 0.10 to 1.0 Mpa (10 to 100 psig). Using appropriate current collectors and supporting structure, polymer electrolyte fuel cells and electrolysis cells should be capable of operating at pressures up to 3000 psi and differential pressures up to 500 psi.

2.2 Thermodynamics Analysis of Fuel Cell

The information about fuel cells' thermodynamics and systems can be used to determine a mass balance around a fuel cell and describe its electrical performance. System analysis requires an energy or heat balance to fully understand the system. The energy balance around the fuel cell is based on the energy components (heat in/out, power produced, reactions, heat loss) that occur in the cell. As a result, the energy balance varies for the different types of cells because of the differences in reactions that occur according to cell type. Polymer electrolyte fuel cells (PEFC) deliver high power density, which offers low weight, cost and volume. The immobilized electrolyte membrane simplifies sealing in the production process, reduces corrosion, and provides for longer cell and stack life. PEMFCs operate at low temperature, allowing for faster startups and immediate response to changes in the demand for power. The PEFC system is seen as the system of choice for vehicular power applications, but is also being developed for smaller scale stationary power [16].

2.2.a Fuel Cell Efficiency: Carnot versus Fuel Cells

The theoretical thermodynamic derivation of the Carnot Cycle shows that under ideal conditions, a heat engine cannot convert all the heat energy supplied to it into mechanical energy; some of the heat energy is rejected. In an internal combustion engine, the engine accepts heat from a *source* at a high temperature (T_h), converts part of the energy into mechanical work and rejects the remainder into a *heat sink* at a low temperature (T_c). The greater the temperature differences between source and sink, the greater the efficiency.

$$\text{Maximum (Carnot) efficiency} = (T_h - T_c)/T_h \qquad [17]$$

where the temperature T_h and T_c are given in degrees Kelvin.

Because fuel cells convert chemical energy directly to electrical energy, this process does not involve conversion of heat to mechanical energy. Therefore, fuel cell efficiencies can exceed the Carnot limit even when operating at relatively low temperature, for example, 80ºC.

There are two ways to convert chemical energy to electrical energy: green route and orange route. The orange route is a general route for the combustion process plus electricity generation in vehicles and power stations that use fossil fuels. The green route is for fuel cells. Fuel cells generate electricity by electrochemical reactions. They bypass the thermal and mechanical energy conversions, hence are more efficient [18].

The operating principles for a fuel cell are simple in concept. The reactants -- hydrogen and air (the oxidant) -- are fed to the cell's electrodes. Ions are transported through the electrolyte sandwiched between the electrodes, creating a current equal to the externally connected load.

While natural gas is the primary fuel, with appropriate cleanup any hydrogen-rich gas -- including gas from landfills, digesters, coalmines, or liquid fuels -- can be supplied to the fuel cell. Note that electricity, heat, water vapor, and carbon dioxide are the products of these basic reactions. Also note that for PEMFC, because of possible Carbon Monoxide poisoning, using pure hydrogen as a fuel is recommended.

The thermal efficiency of an energy conversion device is defined as the amount of useful energy produced relative to the change in stored chemical energy (commonly referred to as the thermal energy) that occurs when a fuel is reacted with an oxidant. Thermal efficiency, η:

$$\eta = \text{Useful energy}/\Delta H \qquad [19]$$

The theoretical efficiency of a fuel cell is related to the ratio of two thermodynamic properties, namely the chemical energy or Gibbs energy (ΔG^0) and the total heat energy or Enthalpy (ΔH^0) of the fuel ($\Delta G/\Delta H$). The fuel cell thermodynamic efficiency is given by the ratio of the Gibbs function change to the Enthalpy change in the overall cell reaction. The Gibbs function change measures the electrical work and the enthalpy change is a measure of the heating value of the fuel.

$$\text{Maximum (Fuel Cell) Efficiency} = \eta = (\Delta G/\Delta H) \qquad [20]$$

Δ T standard conditions of 25°C (298K) and one atmosphere, and water is in the liquid state, the chemical energy ΔH in the hydrogen/oxygen reaction is 285.8 kJ/mole, and the free energy

available for useful work is 237.2 kJ/mole. Thus the thermal efficiency of an ideal fuel cell operating on pure hydrogen and oxygen at standard conditions would be:

$$\text{Maximum (Fuel Cell) Efficiency} = \eta = 237.2 / 285.8 = 0.83 \quad (4)$$

Thus, maximum fuel cell efficiency for the hydrogen fuel cell is 83 percent Kinetic and potential energy changes are assumed to be negligible and steady state operation is assumed.

The efficiency of an actual fuel cell can be expressed in terms of the ratio of the operating cell voltage to the ideal cell voltage. The actual cell voltage is less than the ideal cell voltage because of the losses associated with cell polarization and IR loss. The thermal efficiency of the fuel cell can then be written in terms of the actual cell voltage.

$$\text{The thermal efficiency} = \eta = \text{Useful energy}/\ \Delta H = \text{Useful Power}/\ \Delta G/0.83, \quad [21]$$

Current staying the same:

$$\text{The thermal efficiency} = \eta = \text{Actual Voltage x Current / Ideal Voltage x Current / 0.83} \quad [22]$$

$$\text{The thermal efficiency } \eta = 0.83 \text{ x Actual Voltage/Ideal Voltage} \quad [23]$$

The ideal voltage of a cell operating reversibly on pure hydrogen and oxygen at one (1) atmosphere pressure and 25 degree centigrade is 1.229 V. Thus, the thermal efficiency of an actual fuel cell operating at a voltage of Vcell based on the higher heating value of hydrogen is given by,

$$\text{Thermal efficiency} = \eta = 0.83 \text{ x Vcell/Videal} = 0.83 \text{ x Vcell/1.229} = 0.675 \text{ x Vcell} \quad [24]$$

A fuel cell can be operated at different current densities, expressed as mA/cm^2 or A/cm^2. Decreasing the current density increases the cell voltage, thereby increasing the fuel cell efficiency.

The trade-off is that as the current density is decreased, the active cell area must be increased to obtain the requisite amount of power. Thus, designing the fuel cell for higher efficiency increases the capital cost, but decreases the operating cost.

Hydrogen, a fuel, and oxygen, an oxidant, can exist in each other's presence at room temperature, but if heated to 580^0C, they explode violently. The combustion reaction can be forced for gases lower than 580^0C by providing a flame, such as in a heat engine. A catalyst and electrolyte, such as in a fuel cell, can increase the rate of reaction of H_2 and O_2 at temperature lower 580^0C. Note that a non-combustible reaction can occur in fuel cells at temperatures over 580^0C because of controlled separation of the fuel and oxidant. The heat engine process is thermal; the fuel cell process is electrochemical. Differences in these two methods of producing useful energy are at the root of efficiency comparison issues.

2.3 Fuel Cell Performance

The ideal performance of a fuel cell depends on the electrochemical reactions that occur with different fuels. It is defined by its Nernst potential, and represented as cell voltage.

The maximum reversible voltage provided by the cell can be calculated by using the change in standard free energy.

Change in standard free energy is equal to the number of electrons multiplied by Faraday constant (96,487 coulombs per mole of electrons) that is multiplied by Standard Reversible Potential. This reversible potential changes with changing pressure as given with Nerst Equation:

$$E = E^0 + [(RT/nF)] \text{ x } [\ln (P_{H2} \text{ x } P_{O2}{}^{1/2}) / P_{H2O} \qquad [25]$$

where E is reversible potential changes, E^0 is standard reversible potential changes, n is number of electrons in the reaction, P_{H2} is the partial pressure of hydrogen, P_{O2} is the partial pressure of oxygen, P_{H2O} is the partial pressure of water and it is 1 for water because it is in liquid form. The voltage increase derived from an increase in pressure. The ideal standard potential of an H_2 /O_2 fuel cell is 1.229 volts with liquid water product and it is given as the oxidation potential for H_2 in chemistry textbooks.

The relationship between voltage and temperature is derived by taking the free energy, linearizing the standard condition of 25 degree centigrade, and assuming that the entalphy change does not change with temperature. Where ΔS is change in entropy, the formulation is:

$$\Delta E_r = (\Delta S/nF) \times (T-25^0C) \qquad [26]$$

Different research materials state that the reversible potential decreases with temperature, but the operating voltages of the fuel cell actually increase with an increase in operating temperature. An increase in operating temperature is beneficial for fuel cell performance because of the increase in reaction rate, mass transfer rate and usually lower cell resistance arising from the higher ionic conduction of the electrolyte. On the other hand, it also causes material problems related to corrosion, electrode degradation, electrocatalyst sindering, recrystallization, and electrolyte loss by evaporation, all accelerated at higher temperature.

Theoretically, the power generated by a single fuel cell is the reversible potential times the number of electrons generated per second. Fuel cells are connected in a stack to multiply the power. Useful amounts of electric energy are obtained from a fuel cell only when a reasonable current is drawn. In actuality, cell potential is decreased from its equilibrium potential because of irreversible losses. The losses, which are often called polarization, overpotential or overvoltage, originate from activation polarization, ohmic polarization and concentration polarization. The cell potential is limited by the kinetics of the reaction. Figure 3, the cell potential in volts changes against the cell current density in amperes per square centimeter of cell area. The Figure shows where there is loss occurring (borrowed from Fuel Cell Handbook [13]).

The current cell density represents how fast the reaction is taking place (it is the number of electrons per second, divided by the surface area of the fuel cell electrolyte face); measured voltage divided by reversible voltage is equal to the efficiency. There is an "activation overpotential" to drive the dissociation of the oxygen and hydrogen molecules quickly that needs certain activation energy level to be exceeded, at non-zero current densities. Also, the reaction occurs at the oxygen electrode those are oxidation of the platinum, corrosion of carbon support, and oxidation of organic impurities on the electrode. The total overpotential is 0.1 to 0.2 V, reducing the maximum potential to less than 1.0 V even under open circuit conditions. The activation polarization loss is dominant at low current density.

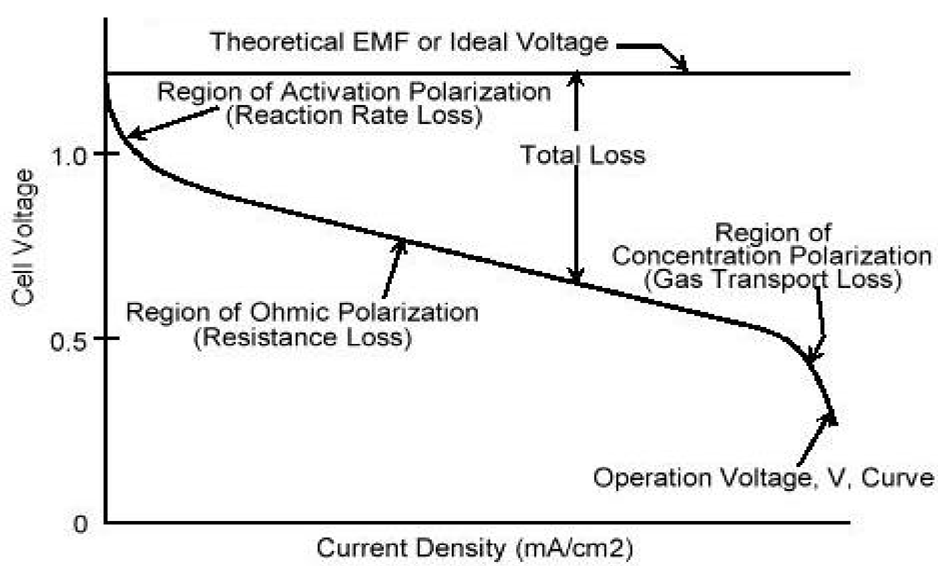


Figure 3 Polarization Curve for Cell Voltage and Current Density

There is also a continuous drop in voltage as current increases due to linear, ohmic losses (i.e. resistance) in the ionic conduction through the electrolyte. The ohmic polarization loss varies directly with current, increasing the whole range of the current because cell resistance remains essentially constant. The thinner the membrane, the lower this loss gets. Thinner membranes are also favorable because they keep the anode wet by "back diffusion of water from cathode" where it is generated.

Finally, at very high current densities (fast fluid flows), mass transport causes a rapid drop-off in the voltage, because oxygen and hydrogen cannot diffuse through the electrode and ionizes fast enough, and products cannot be moved out quickly enough. Mass transport losses occur over the entire range or current density, but these losses become prevalent at high limiting currents where it becomes difficult to provide enough of the reactants flow to the cell reaction sites. The goal of fuel cell developers is to minimize polarization so that voltage per cell approaches the ideal voltage.

For a given cell design, it is possible to improve the cell performance by modifying the operating conditions such as higher gas pressure, higher temperature, change in gas composition to lower the gas impurity concentration. Higher pressure improves kinetics as well as thermodynamics due to the higher concentration of reactants.

2.4 Fuel Cell Performance Variables

The fuel cell performance is affected by operating variables (e.g., temperature, pressure, gas composition, reactant utilization, current density) and other factors (impurities, cell life) that influence the ideal cell potential and the magnitude of the voltage losses. Operating conditions are based on specific system requirements being defined, such as power level, voltage or system weight [27].

Temperature and pressure on the ideal potential of a fuel cell can be analyzed on the basis of changes in the Gibbs free energy with temperature and pressure. Because the entropy change for the H_2/O_2 reaction is negative, the reversible potential of H_2/O_2 fuel cell decreases with an increase in temperature by 0.84 mV/degree centigrade (reaction product is liquid water) [13]. For the same reaction, the volume change is negative; therefore, the reversible potential increases with an increase in pressure. An increase in operating temperature is beneficial to fuel cell performance because of increase in reaction rate, higher mass transfer rate, and usually lower cell resistance arising from the higher ionic conductivity of the electrolyte. In addition, the CO tolerance of electrocatalysts in low temperature fuel cells improves as the operating temperature increases. These factors combine to reduce the polarization at higher temperatures. On the negative side, material problems related to corrosion, electrode degradation, electrocatalyst sintering and recrystallization, and electrode loss by evaporation are all accelerated at higher temperatures.

An increase in operating pressure has several benefits on fuel cell performance because the reactant partial pressure, gas solubility, and mass transfer rates are higher. In addition, electrolyte loss by evaporation is reduced at higher operating pressures. Increased pressure also increases system efficiencies. However, increased pressure brings material problems, parasitic power cost, thicker piping, and additional expenses for the compression process.

The reactant utilization and gas composition have a major impact on fuel cell efficiency. Fuel and oxidant gases containing a higher concentration of electrochemical reactants produce a higher cell voltage [13].

SECTION 3

3.1 Conceptual Design and Fabrication of the Proton Exchange Membrane Fuel Cell

Proton Exchange Membrane Fuel Cell, or polymer electrolyte membrane (PEM) are the best for mobile applications because of low weight, cost and volume [28]. The immobilized electrolyte membrane simplifies sealing in the production process, reduces corrosion and provides for longer cell stack life. It operates at low temperature, allowing for faster start-ups and immediate responses to changes in the demand for power.

Essentially, each fuel cell contains membrane electrode assembly (MEA), which consists of the polymer ion-conduction membrane with flat electrode sheets attached to either side. Oxygen and hydrogen are channeled to the cathode and anode sides, respectively, in flow fields carved or pressed into plates that are next to the electrodes. These plates are called separators that can be a single plate serving both sides for two adjacent electrodes or two separate plates serving individual electrodes. The membrane must pass hydrogen ions but not electricity; the plates must conduct electricity, but not allow water, hydrogen, or oxygen to permeate through. The separators are made from graphite and are expensive. Each fuel cell membrane requires cooling plates periodically interspread between the active cells.

Cooler cells allow flow of the coolant within the stack, and are essentially flow fields through which only water can pass. A cooler cell to active cell ratio of 1:2 is common to use. Cooler cells are made identical to active cells to reduce the cost of manufacturing and include parts such as separator plates (one or two), coolant flow fields, and gasket. In the repeating cells, the stack requires an electrically insulated plastic housing, tie rods to hold the cell together, current collectors at the end of the stack to conduct electricity to power system and insulators and endplates over the current collectors.

The membrane is usually a perfluorosulfonic acid polymer. This is a polytetrafluoroethylene (PTFE), trade name Teflon). One common PEM is Nafion, manufactured by DuPont. It is sometimes classified with the compounds known as superacids because they are stronger than pure sulfuric acid. Nafion is currently being sold at $333.90 (0.007 - inch thickness and 12x12 - inch sheet). This product can be dissolved only at high pressure in autoclave and will swell with organic solvents that are miscible with water. Nafion membranes have increases ion-exchange capacity when wet because the membrane swells. The linear expansion of the membrane at a 23 degrees centigrade for the Nafion 117 membrane is 16 percent in one direction and 16 percent in the other [15]. Nafion is porous material; therefore, even at substantial (100psi) pressure differences it will not allow significant mass transport. It will allow the transport of small polar molecules (water, CH_3OH, urea etc.) as a result of differences in concentration and electrical potential. General chemical structure of the Nafion is:

$[(CF_2CF_2)nCFCF_2]xCF_3\ (OCF_2CF)_m\ OCF_2\ SO_3H$

The superacidity of the sulfonic acid group is attributable to the electron-withdrawing ability of the perfluorocarbon backbone. The ratio of (m) to (n) (active chain monomers to inactive chain monomers) determines the acidity of the electrolyte.

The thinness of the polymer electrolyte allows building densely packed stacks and achieves high power densities and also allows high conductance and low ohmic resistance losses. On the other hand, if the membranes become overwet due to production of water at the cathode, diffusion of reactants gets blocked. Also platinum is required, less than 0.4 $mg.cm^2$ for each anode and cathode, mainly to resist the effects of carbon monoxide poisoning from impure hydrogen. Pt/Ru alloys are often used at the anode alloy in order to prevent carbon monoxide poisoning because Rubidium changes the lattice constant of the resulting catalyst and makes carbon monoxide absorption more difficult.

The present electrodes are cast as thin films and bonded to the membrane. Low platinum loading electrodes (less than 0.6 mg Pt/cm^2 cathode and less than 0.25 mg Pt/cm^2 with 0.12 mg Ru/cm^2 anode) and high platinum loading electrodes (4 to 8 mg Pt/cm^2) have been tested in the industry and achieved 600 mA/cm^2 at 0.7 V. To improve utilization of the platinum, a soluble form of the polymer is incorporated into the porosity of the carbon support structure. This increases the interface between the electrocatalyst and the solid polymer electrolyte (ElectroChem Inc. Product Information). Electrochem sells carbon electrodes on a request basis that might cost $2525 per electrode if the order is 20 percent electrodes, and 20 percent Pt on Vulcan XC-72 for $2650 per electrode if the order is 20 percent electrode. The prices may be reduced if the mass order comes in.

Most PEM fuel cells use machined graphite plates for current collection and distribution, gas distribution and thermal management. Cooling is accomplished by using a heat transfer fluid, which is usually water, which is pumped through integrated coolers within stack. One reason that PEM fuel cells operate less than 100^{0}C is because higher temperatures remove water from the membrane. At this low temperature catalyst are not as active. More catalyst is required at the cathode than at the anode due to the much lower activity of oxygen ionization.

Carbon monoxide (CO) binds strongly to platinum sites at temperature below 150^{0}C, which reduces the sites available for hydrogen chemisorption and electro-oxidation. Because of CO poisoning of the anode, only a few ppm of CO can be tolerated with the platinum catalysis at 80^{0}C. Because reformed hydrocarbons contain about one percent of CO, a mechanism to reduce the level of CO in the fuel gas is needed.

Water management of PEM fuel cell is very important because it has a significant impact on cell performance. Water is produced in liquid form. A critical requirement of the cell is maintaining higher water content in the electrolyte to ensure high ionic conductivity. The ionic conductivity is higher when the membrane is fully saturated, and this offers a low resistance to current flow and increase overall efficiency. The water content in the cell is determined by the balance of water or its transport during reactive mode of operation. The Water-drag through the cell, back diffusion from the cathode, and diffusion of any water in the fuel stream through the anode are other contributing factors. Water transport is a function of the cell current and the characteristics of the membrane and the electrodes.

Without adequate water management, there is improper balance between water production and evaporation within the cell. Adverse effects include dilution of reactant gases by water vapor, flooding of the electrodes, and dehydration of the solid polymer membrane. The adherence of the membrane to the electrode also will be adversely affected if dehydration occurs. Close contact is very important between electrodes and electrolyte membranes because there is no free liquid electrolyte to form a conducting bridge. If more water is exhausted than produced, it is important to humidify the incoming anode gas. If there is too much humidification, the electrode floods, causing problems with diffusing the gas to the electrode. There have been attempts to control the water in the cell by using external wicking connected to membrane to either drain or supply water by capillary action. An alternative way to control water may be to humidify incoming gases. The scientist to use temperature rise between inlet and outlet of the flow field to increase the water vapor carrying capacity of the gas streams is exploring another option.

3.2 Conceptual Design and Fabrication of the Power Car System with PEMFC

Although a fuel cell produces electricity, a fuel cell power system in automobile application requires the integration of many components beyond the fuel cell stack itself. An electric drive system that operates on a fuel cell requires a fuel cell stack, fuel cell subsystems including cooling system, air intake, hydrogen intake, humidification system (if any), hydrogen storage device, electric motor(s), motor controller, transmission and chain, and battery for startup. Note that the fuel cells produces DC power and utilize only processed fuel.

A fuel cell system consists of a fuel processor, fuel cell power section, power conditioner, and potentially a cogeneration or bottoming cycle in order to utilize the rejected heat. The design of the fuel cell system involves optimization with respect to efficiency and economics and minimization of cost. Often, these objectives are conflicting and decisions must be made.

Electrical motors operate on the base principle that a current-carrying wire in a magnetic field will experience a force. The magnetic field can be generated by permanent magnets or by a current in an electromagnet. The stator is stationary and produces the magnetic flux, while the rotating armature or rotor contains the coils that carry the armature current. In general, motor speed is controlled by increasing the armature voltage, while torque is controlled by increasing the current flowing through the armature.

- **DC Motors**: They employ a fixed current that causes the rotor to “want” to turn to line up with the poles in the stator. However, the current in the stator is commutated, often by a split-ring brush system, so that the direction of the current in the poles switches as the rotor passes by. This ensures that the rotor stays in continual motion. Multiple sets of poles are used to smooth out the rotation. In general, controllers are cheaper than for AC motors; on the other hand, the motors themselves tend to be bulkier and heavier and more expensive.

- **AC Motors:** Alternating current (AC) motors are inexpensive, simple, and reliable. They operate by taking advantage of the changing phase of the stator current. AC motor control is expensive and also requires an inverter to produce AC from the fuel cell.
- **Controller**: The Controller controls speed, direction and optimizes energy conversion. It connects the power source–fuel cell–into the actual motor. The voltage output by fuel cells varies as a function of power. Some controllers require a DC-to-DC converter to step down this changeable voltage to the motor's expected constant operating voltage, but other controllers incorporate a DC-to-DC converter and can accept a varying voltage. In either case, DC-to-DC conversion losses are minimized if the fuel cell output voltage is near the operating voltage. Converter efficiencies are typically greater than 90 percent.
- **Fuel Processor**: The fuel processor sends fuels to PEM fuel cell, which must be free of CO It depends on both the raw fuel and the fuel cell technology. PEMs can use methane directly, but a special catalyst is needed and performance is penalized. Fuel also needs to be cleaned from contaminants. When hydrogen is supplied directly to the fuel cell, the fuel processing section is just a delivery system. This approach can be used in automobile applications.
- **Fuel Cell Power Section**: Fuel Cells Power Section is constructed in series so voltages from each cell add up and the same current flows through the entire stack. The fuel cell engine is made of several electrically and physically connected cells in a box-shaped stack. In fuel cell stacks, cells are arranged so that protons pass through the membrane, while electrons are conducted by separating graphite plates in the opposite direction.

Membranes must be kept wet so that they can conduct the hydrogen ions (protons). The hydrogen and oxygen flow in molded manifolds build on the side of the stack, and are divided into parallel feed into the individual cells. Water and exhaust gases are collected in another manifold and rejected to the atmosphere (the water may be recycled to humidify the incoming gases).

- **Power Conditioning:** The power conditioning is system used to convert power and includes equipment of DC to AC inversion and current, voltage and frequency control, stepping the voltage up or down through a transformer depending on final equipment utilization voltage and maintaining harmonics output to an acceptable level. In addition, transient response of the power conditioning equipment should be considered. The initial phase of systems analysis, the aspect of power conditioning, is the efficiency of the power conversion and incorporation of the small power loss into the cycle of efficiency. For specific applications, fuel cell can be used to supply DC power distribution systems designed to feed DC drives such as motors.
- **Gas Flow Subsystem:** Oxygen and hydrogen are introduced into the fuel cell system at the appropriate flow rate required for the current at any given moment; this requires a variable-flow system if the stoichiometry is to be kept constant. Even in an "atmospheric-pressure" system, some pressure over atmosphere is needed in order to push the gases through the often-serpentine passages carved into the flow plates, and to force liquid water out of the same passages. Gas flow management is an important issue that must be dealt. Due to the fact that the cathode reaction is much slower than the anode reaction, oxygen is often supplied at a higher-than stochimetric flow rate. The ratio of air flow rate to the minimum flow rate required for stochiometric oxygen-hydrogen reaction is often

2.0 or higher in order that the concentration of oxygen in the air not drop too much as it passes through the flow field, and the excess air also helps to push product water generated at the cathode out of the fuel cell. An air filter is needed to prevent foreign objects from being taken into the fuel cell. Hydrogen is supplied dead-ended and there is 100 percent hydrogen utilization. Dead-ended fuel cells still need to vent occasionally in order to purge impurities that may have entered the fuel cell; this involves opening the anode exhaust valves for a brief period and allowing the hydrogen to flow directly into the atmosphere for a very brief time. Effective utilization is slightly less than 100 percent. To manage the air flow, blowers are used in atmospheric systems to draw air into the fuel cell; no corresponding device is needed for the hydrogen side because in all current designs, the hydrogen is kept under pressure higher than the operating pressure of the fuel cell, and expands as it is released from the storage container or produced above atmospheric pressure in a reformer.

- **The Blower:** The blower is used for managing air flow, and typically powered electrically from the fuel cell output, with a battery required startup.
- **The Air Input Compression**: The air input compression process is used to control the optimal stochiometry. They increase the concentration of oxygen per volume per time–its effective partial pressure– and thus increase the fuel cell efficiency. Because most of the hydrogen storage techniques involve pressurized hydrogen, it is not difficult to obtain a matching pressurized hydrogen stream; in any case, a typical PEM can tolerate a pressure difference of about 0.5 bar using Nafion-115 as membrane. In a tightly integrated system, the compressor can be powered mechanically as a turbocharger, using a shaft attached to a turbine running off the exhaust from the fuel cell. This allows recovery of some of the

expansion work. On the other hand, the system may be simpler if the compressor is powered only by an electric motor, with separate battery for startup purposes.

- **Heat Issue**: A higher operating temperature means that more of the product water is vaporized, so that more waste heat goes into the latent heat of vaporization and less liquid water is left to be pushed out of the fuel cell. Heat rejection is also abetted at higher temperatures due to the larger difference between the fuel cell temperature and ambient temperature. On the other hand, lower stack temperature means shorter warm-up times for the system as a whole, and lower thermomechanical stresses. Rejected heat, which is heat not utilized in fuel processing and fuel cell subsystem, can be used to provide heat or additional electricity. Cooling can be achieved through a number of means. First, the evaporation of some of the product water at the cathode absorbs some heat. Second, active cooling with air or liquid coolants can be used to transfer heat to radiators. Third, passive cooling of the fuel cell can be performed with cooling fins and heat sinks. Finally, the fuel cell might be coupled with subsystems that absorb heat like turbine reheaters and metal hydride containers.
- **Hydrogen Storage:** This can be done through direct hydrogen storage in automobile application. On-board hydrogen storage brings up the issue of safety because hydrogen can often be thought of as dangerous fuel. This is because unlike gasoline and most hydrocarbons, which only ignite over a narrow range of fuel-to-air ratios (for example, about 1.3 – 7.1 percent for gasoline), hydrogen can ignite over a wide range of concentration (4 percent - 75 percent in air). Also, hydrogen has relatively low ignition energy; a low energy spark can begin an almost invisible flame. To overcome this, odorants could be added to hydrogen in the same way that they are added to natural gas,

except that most sulfur-containing compounds poison platinum catalysts; also, only pure hydrogen can be used in dead-ended systems, because other substances would accumulate in the blocked supply channel. Safety devices can also be designed to shut down power to the battery and cut off hydrogen flow in the case of a collision. Another alternative mentioned in the literature is metal hydride energy storage. It is said that metal hydrides, which are formed when metal atoms bond with hydrogen to form stable compounds, are a good option. Liquid hydrogen storage is too expensive, difficult to handle, and inefficient for the low storage requirements of cars. Chemical hydride storage needs future developments to demonstrate their practicality. Due to their inherent safety, decent hydrogen gravimetric density, and excellent volumetric density, metal hydrides are a good choice for cars. They offer important sides benefit that of acting as a heat sink for waste fuel cell heat. One difficulty is refueling; because metal hydride tanks are likely to more than $100, swapping fresh packs for old is not likely to be a viable distribution model unless modular units can be made that satisfy a fraction of the refueling need. Refueling at hydrogen pumping stations, an inferior distribution option, is likely necessary but not impossible. Ford Motor Co. research vice president Bill Powers explains details of Ford's new hydrogen gas station and of the fuel cell-powered P2000 prototype during a press conference (24). Compressed gas cylinders at 3600 psi are a better-established technology, but they have drawbacks of lower safety and poor perception of safety.

Finally, the purpose of vehicle modeling is to convert input parameters (performance measurements like desired range, driving cycle that must be sustained, and types of power and storage components) into the output parameters of curb weight, size of engine required, heating system design, cost and convenience.

Speed of a vehicle is determined by the output of its engine. Motor's torque and angular velocity are important characterizations. To design car systems using fuel cells, one needs to know what kind of power is needed under which conditions.

In this project, a prototype fuel cell operated vehicle system is developed without considering the torque. The Power Wheel Toy Car that is used in this project was designed to operate with a 6-volt battery. This car is designed for maximum 50 lbs. (23 kg) weight, 2.5 mph (3.6 km) forward speed. Alteration of the car was not considered within the scope project.

SECTION 4

4.1 Experimental Apparatus, Design and Procedures of a Mini Fuel Cell Kit

A. The Mini Fuel Cell Kit

The mini fuel cell kit has been used to understand the basics of fuel cell technology and to get some data. The experiment was conducted to determine the voltage and current output of various numbers of fuel cells and varying volumes of methanol and sodium hydroxide.

Most fuel cells use hydrogen as fuel, but hydrogen is difficult to obtain and safely handle in school laboratories [29]. Thus, the mini kit has been designed to use easily obtained and manipulated liquid fuels. Methanol will be used, but other chemicals can also be used such as methanoic acid and methanal.

Hydrogen fuel cells give more power than methanol [30]. In the fuel cell kit, one Molar Sodium Hydroxide (NaOH) was used as the electrolyte with methanol (CH_3OH) as the fuel. The cathode was a non-precious metal catalyst with PTFE binder on nickel mesh10 cm^2; the anode was platinum on Vulcan XC72 with PTFE binder on nickel mesh. Typical current was expected at 30^0C with 1 M KOH about 120mA at 0.4 V with methanol fuel, which is enough to turn small 1.5V electric motors. Higher currents can be obtained in the cell, somewhat warmed. Conversely, less current will be obtained in a cold laboratory. Higher concentrations allow higher currents to be drawn because the internal resistance is less.

B. Experimental Procedure:

First the electrolyte, NaOH, is poured into the anode (beaker) up to a fill mark (which was approximately 65 ml). Then the CH_3OH, 10ml, was added to it. The cathode was then inserted into the beaker (8 cathode/beaker assemblies total) and swirling the fuel cell apparatus ensured mixing of the electrolyte and fuel.

C. Apparatus

One Molar NaOH and CH_3OH, fuel cell kit (includes anode and cathode beakers) are used as the apparatus. Figure 4 shows the physical setup for the actual tests. The eight fuel cell units on the left are connected in series to produce the desired voltage. The wall clock is connected to the output voltage.

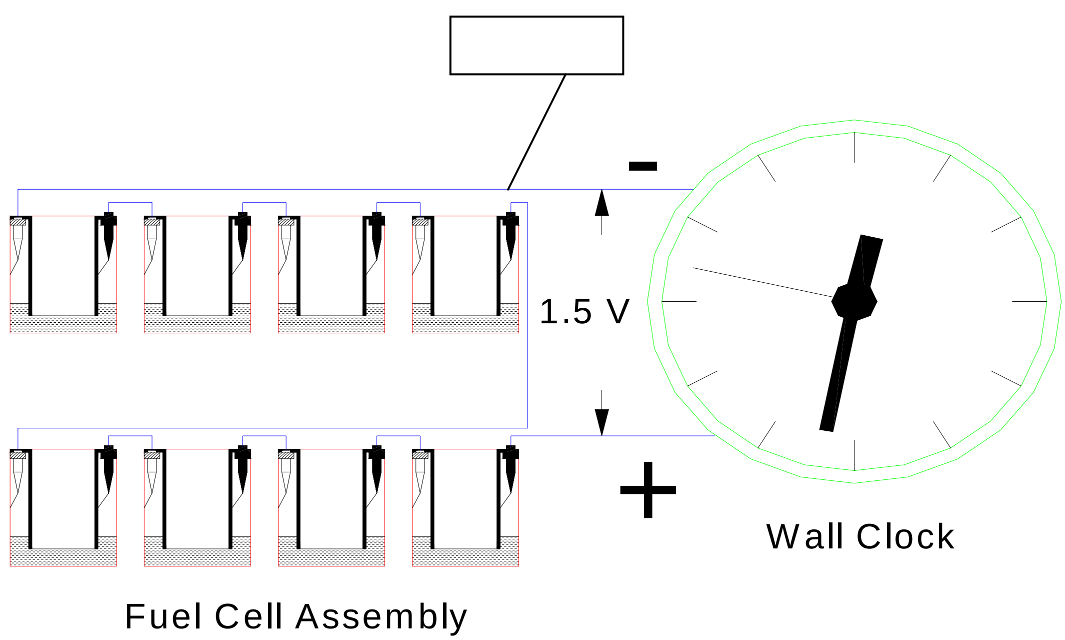


Figure 4. Schematic Diagram of the Mini Fuel Cell Apparatus

D. Experimental Results and Discussion

The experimental results of a Mini Fuel Cell Kit are shown in the Table 1. Figures 5 and 6 show the relationship between the voltage and number of cells, and the current and the number of cells. From Figures 5 and 6, the number of cells increases from two to eight, and voltage increases from 0.9 to 2.983 V. The diagrams show that there is a change in voltage with increasing number of fuel cells. It is concluded that the number of cells effect the voltage and current. This experiment proves what was known in the industry all along. Fuel cells are used in series to increase the voltage.

Figures 7 and 8 have the same experiment conducted as in Figures 5 and 6 at two different levels with a different volume of fuel and electrolyte. The number of cells was four and eight. Voltage increased from 2.340 to 4.950 V, along with current from 0.13 to 0.22 A. Even though Figure 8 shows a linear relationship between variables, it cannot be concluded that there is a direct positive relationship because there are only two data points. One conclusion that can be drawn is that the volume of the electrolyte and fuel affect the outcome of voltage and currency, which ties in with larger fuel cells, larger voltage and current can be withdrawn.

The results were a little different than what the manufacturer of this kit suggested it would be. One of the major factors of the results' difference from what the manufacturer had in their pamphlet and what was drawn in the lab was due to the difference in the fuel cell electrolyte and concentration of that electrolyte. KOH was recommended to be used in the experiment because of its high conductivity. But, due to availability, NaOH was used. The fuel cell that was used in this experiment was methanol. The experiment was conducted at full concentration, which was 65 ml electrolyte and 10 ml methanol as fuel and, 32.5 ml electrolyte and 5 ml fuel. These concentrations were also tested using different numbers of individual fuel cells.

It is concluded that the mini fuel cell kit test was successful and that voltage and current was drawn from an open circuit. The differences in the results in the mini cell kit were due to the electrolyte type, concentration and number of fuel cells that were used. The electrolyte that was used in our fuel cell device was Sodium hydroxide (NaOH), one (1) molar concentration. Whereas the electrolyte suggested in the test procedure was Potassium (KOH). The Volume of the electrolyte and fuel did have an effect on the outcome. The number of cells obviously had a significant impact on how much voltage could be drawn from the system.

Table 1 The Experimental Results of the Mini Fuel Cell Kit

	Concentration molar	Volume/ml	No. Cells in series	Voltage/Volt	Current/Amp.
NaOH	1 Molar	32.5	8	4.950	0.22
CH_3OH		5			
NaOH	1 Molar	32.5	4	2.340	0.13
CH_3OH		5			
NaOH	1 Molar	65	8	2.983	0.73
CH_3OH		10			
NaOH	1 Molar	65	6	2.279	0.67
CH_3OH		10			
NaOH	1 Molar	65	4	1.221	0.46
CH_3OH		10			
NaOH	1 Molar	65	2	0.900	0.30
CH_3OH		10			

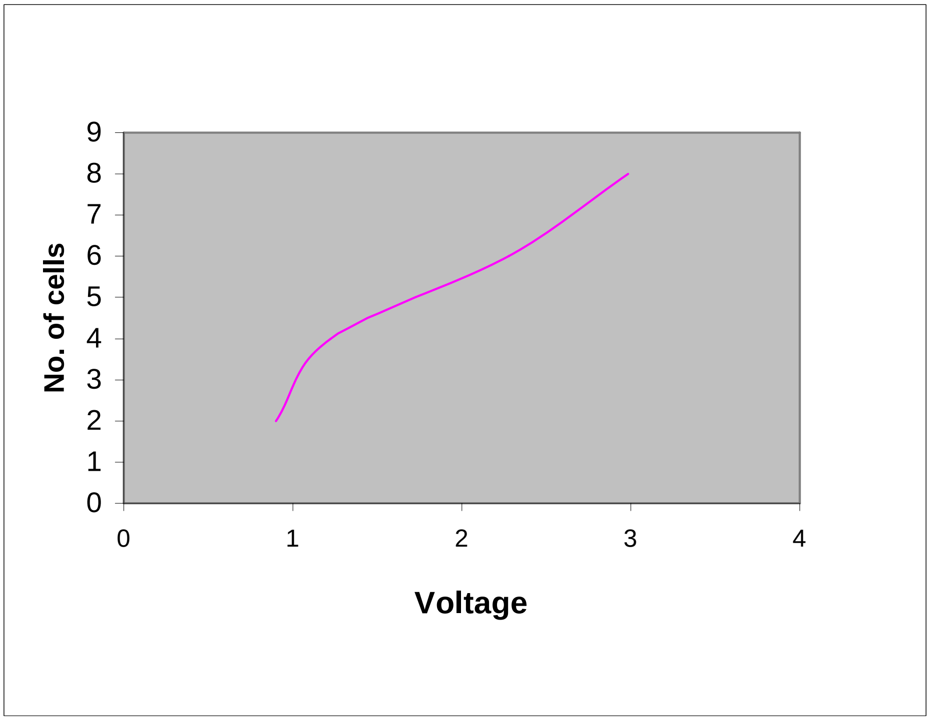


Figure 5 The Voltage Changes With Number of Fuel Cells (65 ml NaOH and 10 ml CH_3OH)

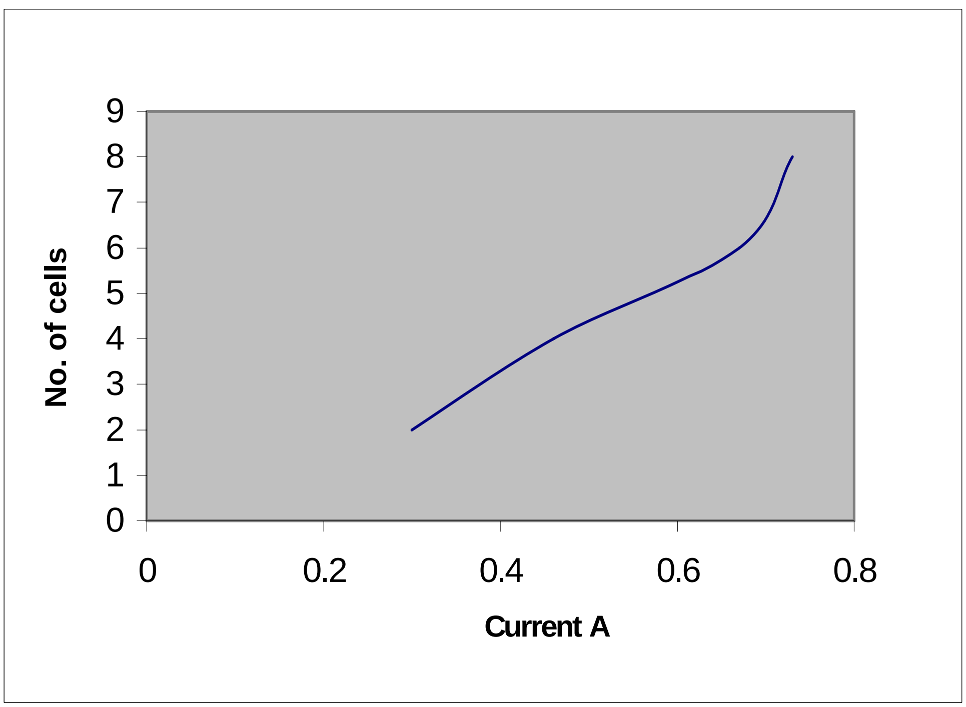


Figure 6 The Current Changes With Number of Fuel Cells (65 ml NaOH and 10 ml CH3OH)

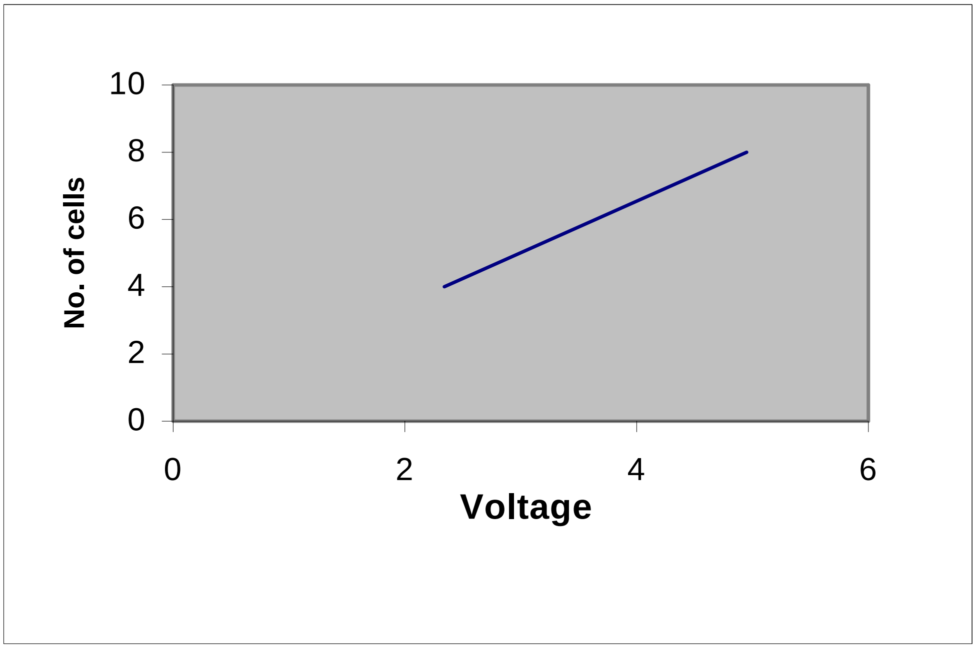


Figure 7 The Voltage Changes With Number of Fuel Cells (32.5 ml NaOH and 5 ml CH_3OH)

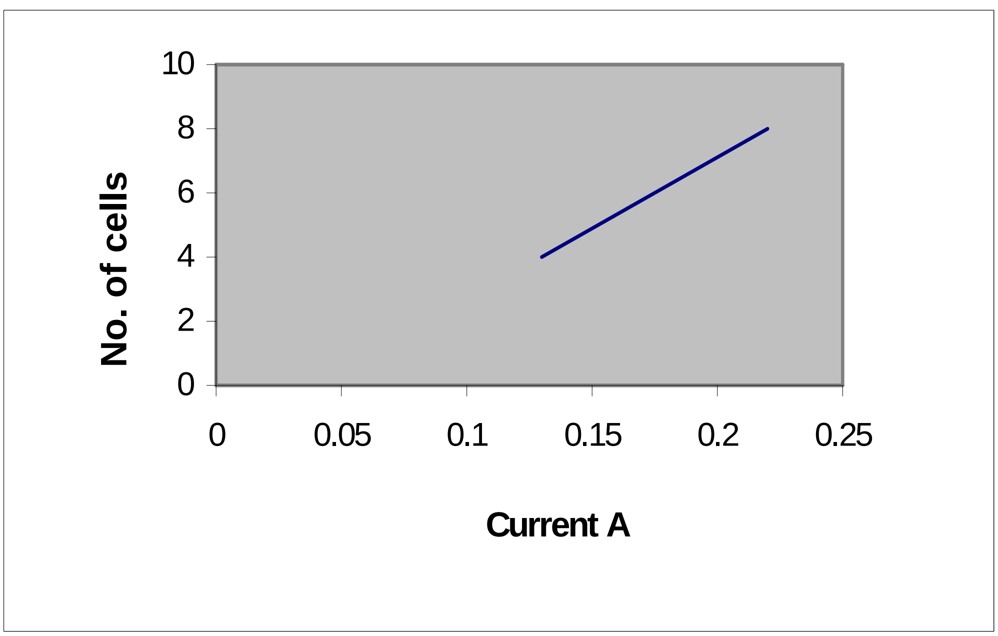


Figure 8 The Current Changes With Number of Fuel Cells (32.5 ml NaOH and 5 ml CH_3OH)

4. 2 Concentration effect on the experimentation of the Mini Fuel Cell Kit

Mini Fuel Cell experimentation is repeated using Potassium Hydroxide (KOH) as an electrolyte, and methanol (CH_3OH) as a fuel. This time, experiments were conducted using a different concentration of electrolyte with changing fuel concentration.

Electrolyte (KOH) was prepared as 1 Molar and 2 Molar concentrations. The mixture of electrolyte was prepared with 5 ml and 10 ml methanol. The laboratory was room temperature. Experiments were conducted on the same day, and results were as follows:

Table 2. Experimental Results of Different Concentration Level of Electrolyte (KOH) and Fuel (CH_3OH)

1 Molar KOH - 65 ml, 5 ml CH_3OH		
Number of Cells	**Voltage**	**Ampere**
2	0.093	0.1
4	0.192	0.1
6	1.606	0.1
8	1.626	0.1
1 Molar KOH - 65 ml, 10 ml CH_3OH		
Number of Cells	**Voltage**	**Ampere**
2	0.085	0.1
4	0.203	0.1
6	1.64	0.1
8	2.264	0.1
2 Molar KOH - 65 ml, 5 ml CH_3OH		
Number of Cells	**Voltage**	**Ampere**
2	0.062	0.1
4	0.099	0.1
6	0.1	0.1
8	0.158	0.1
2 Molar KOH - 65ml, 10 ml CH_3OH		
Number of Cells	**Voltage**	**Ampere**
2	1.28	0.1
4	2.276	0.1

6	2.926	0.1
8	3.057	0.1

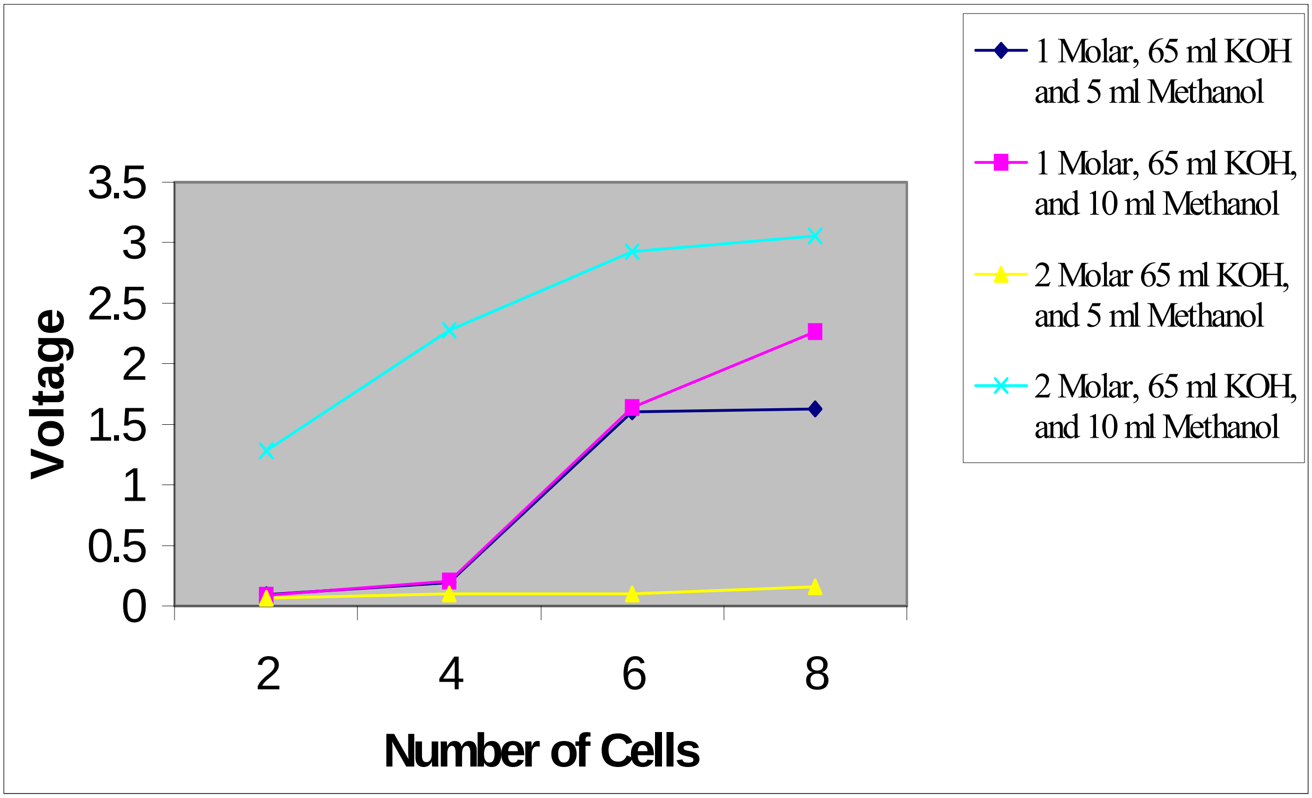


Figure 9 The Voltage Changes With Number of Cell
(With Respect To Concentration Differences in Electrolyte and Fuel.

Graphical illustration, Figure 9, shows that different concentration of electrolyte and fuel result in different voltage.

2 Molar, 65 ml electrolyte (KOH), and 5 ml Methanol mixture gave the least amount of voltage that can be drawn from the system. As the number of fuel cells increased from two to eight, voltage increased from 0.062 to 0.158.

2 Molar, 65 ml electrolyte (KOH), and 10 ml Methanol gave the higher voltage increase (from 1.280 to 3.057), as number of fuel cell increased from two to eight. It can also be noted that

the voltage drawn, where there are only two cells used, is much higher than the mixture of 2 M KOH and 5 ml.

1 Molar, 65 ml KOH, and 5 ml Methanol yield increase in voltage from 0.093 to 1.626 as number of fuel cells increased from two to eight. When the mixture contained 10 ml Methanol, even though the initial voltage draw was 0.085, which is less than 0.093 with 5 ml Methanol, the voltage exceeded the original mixture voltage 1.626 when the number of fuel cells increased to 8 with 2.264 volt.

Results of these experiments show that an increase in concentration of a fuel and electrolyte has an impact on how much voltage can be drawn in a fuel cell system. In the first set of experiments, we have already shown that the number of fuel cells had an impact on the voltage of the fuel cell. The second set of experiments showed there is an equilibrium point where electrolyte and the fuel concentration are comparable to each other that yield the higher voltage generation. From the results and figures, 1 mo lar and 2 molar electrolyte did not give increasing voltage but amount of methanol that is included in the mixture made a big difference.

There weren't not any current changes in the changes that were made. The current changes were expected because of the increased number of fuel cells and it was concluded that the experiment needed to be repeated.

Experiments have been repeated for the same concentrations two different times because a solid conclusion could not be drawn from the first one, with respect to current. Numerical results have been shown in Table 3. These experiments have been conducted on different days where there may have been small temperature differences in the room where experiments were conducted.

The results of the second set of experiments show differences between levels of concentration in terms of drawn voltage and current. It also shows that voltages drawn at different levels of concentration increase as number of cells increase.

Table 3 Experimental Results of Different Concentration Level of Electrolyte (KOH) and Fuel (Experiment conducted on two different days).

		2M KOH, 10 ml CH_3OH	**2M KOH, 5 ml CH_3OH**	**1M KOH, 10 ml CH_3OH**	**1M KOH, 5 ml CH_3OH**
Day 1	**# of cells**	**Voltage**	**Voltage**	**Voltage**	**Voltage**
	2	1.268	1.288	1.257	1.408
	4	2.184	2.214	2.234	2.239
	6	2.404	2.509	2.509	2.444
	8	2.649	2.804	2.699	2.664
		Amperage	**Amperage**	**Amperage**	**Amperage**
	2	0.02	0.01	0.02	0.04
	4	0.03	0.03	0.05	0.05
	6	0.59	0.35	1.03	1.6
	8	2.26	1.41	3.07	3.99
Day 2		**Voltage**	**Voltage**	**Voltage**	**Voltage**
	2	1.136	1.279	1.211	1.173
	4	2.184	2.334	2.199	2.274
	6	2.574	2.659	2.484	2.594
	8	2.814	2.864	2.833	2.701
		Amperage	**Amperage**	**Amperage**	**Amperage**
	2	0.02	0.01	0.03	0.02
	4	0.03	0.02	0.05	0.03
	6	0.19	0.2	0.62	0.24
	8	2.22	1.35	2.94	3.19

The results show repeated experimentation for the third time on a different day with the same concentrations and same number of fuel cells. Results have shown that with the increased number of fuel cells, there is a voltage and currency increase. The trend of these results is upward and tells us that with the number of fuel cell increase as voltage drawn increases.

These results also showed that there is a difference in current drawn as concentration of electrolyte and fuel mixture changes. One (1) Molar KOH as electrolyte and 5 ml CH_3OH as fuel gave the best results in current drawing as the number of fuel cells increased. This mixture combination was what the manufacturer of this mini fuel cell had suggested in their pamphlet. Again, first experimentation (Table 2) did not show any current increase. The second experimentation showed significant current increase as the number of fuel cells increased. This aligned with the literature say and industrial experimentations show. It is said in literatures that as the area of electrolyte increases, which corresponds to increase in number of cells used in the experiment, current drawn is expected to increase. One can also see that the concentration of electrolyte and fuel mixture made a difference in how much current can be drawn.

Repeated experimentation results (Table 3), with respect to current with same concentrations, shows that the current results were similar when the number of cells were low, namely two and four. The differences were larger as the number of cells increased to six and eight. It can be concluded that the area of the electrolyte increases as the number of fuel cells increase, which results in larger current draws. In this case, one molar KOH and 10 ml methanol (CH_3OH) gave the most significant result.

Figures 10 and 11 are combined experiments shows results from the second and third repeat. The first experimentation results were not included in these graphics since there were no conclusions that could be drawn from it.

In summary, the results of these three sets of experiments could not predict whole performance of concentration level of electrolyte. Because of the primitive experiment apparatus that was suppose to show the working principles of fuel cell, consistent results could not be drawn. Also, an increase in activation might be the cause of losing the current in the first experiment.

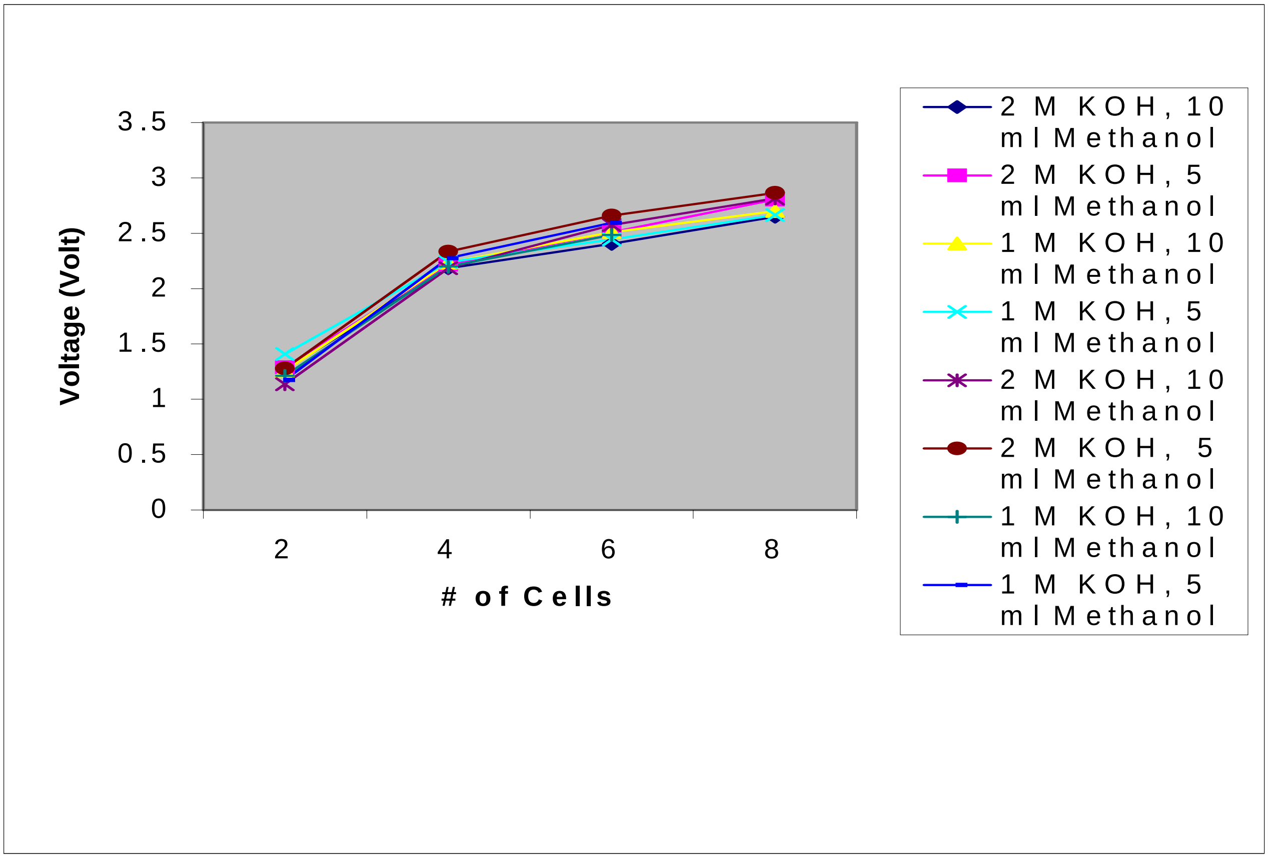


Figure 10 The Effect of Concentration Differences in Electrolyte and Fuel on Voltage Drawn. (Combination of second and third repeated experiments).

Activation polarization is prevalent in low current density. The mini fuel cell kit provided low current density; therefore, the rate of the electrochemical reaction at one of the electrodes surface might be controlled by sluggish electrode kinetics. A solution for the activation polarization loss could be the use of a regulator or controller in a prototype. These experiments have shown that fuel cells work. With the chemical reaction, voltage and current can be drawn and be used to power electrical devices. To get consistent results from fuel cells, other parameters have to be considered such as regulator, cooler, continuous fuel supply etc.

Tables 2 and 3 show that fuel cells can generate voltage and current. Voltage and current drawn increases as the number of fuel cells increase. Each cell generates a certain amount of voltage that adds up at the end. Currency is determined by the area of the electrolyte that is used. With the open system such as the mini fuel cell kit, the results may not be consistent.

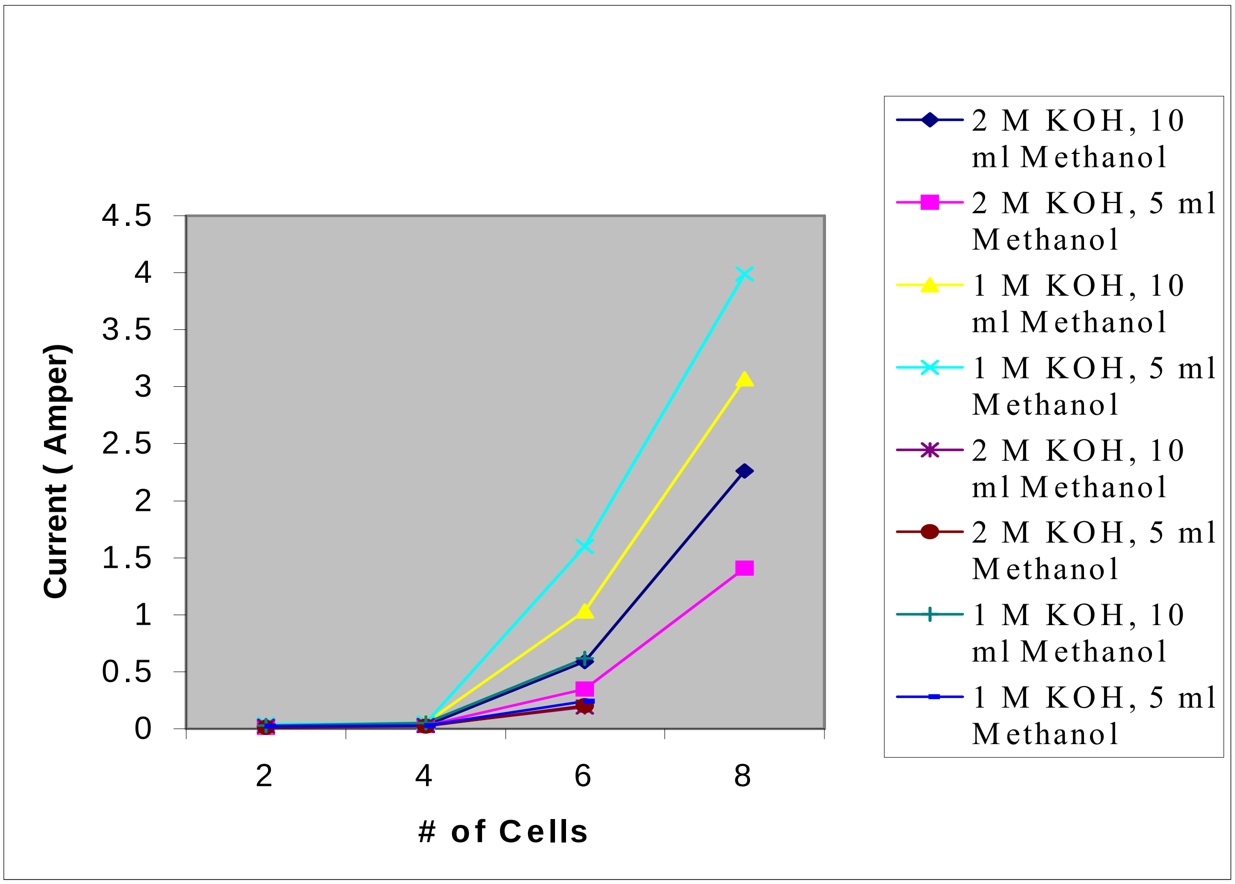


Figure 11 The Effect of Concentration Differences in Electrolyte and Fuel on Current Drawn (Combination of second and third repeated experiments).

It is concluded that for any application of the fuel cell, the system has to be built to actually use the voltage and currency generated.

ANOVA Table is prepared to show the relationships between experimental variables. Minicab 12 for Windows software is used to create ANOVA Table (Table 4).

Table 4 Factorial Design on days vs. # of cells vs. concentration with outcome of voltage

General Linear Model						
Factor	Type		Levels		Values	
Days	Fixed		2		1 2	
Number of cell	Fixed		4		1234	
Concentration	Fixed		4		1234	
Analysis of Variance for C7, using Adjusted SS for Tests						
Source	DF	Seq. SS	Adj SS	Adj MS	F	P
Days	1	0.0091	0.0091	0.0091	1.83	0.188
Number of cells	3	10.4686	10.4686	3.4895	704.65	0.000
Concentration	3	0.0362	0.0362	0.0121	2.43	0.089
Error	24	0.1189	0.1189	0.0050		
Total	31	10.6327				

Unusual Observations for C7

Ob	Fit	StDev	Fit	Residual	St Resid
17	1.40800	1.23256	0.03519	0.17544	2.88R

R denotes an observation with a large standardized residual.

ANOVA table is prepared with outcome data of voltage. Days, number of cells and concentration are taken as factors that might affect the experiment. *F* value is found to be 4.26 where Alfa is 0.05. Here *F* value is 1.83 for the days and that concludes that days are not a significant factor in the experiment where Alfa is 0.05. P value 0.188 also shows where Alfa is equal or less than 0.05, days are not a significant factor. Concentration F value is found to be 3.01 at Alfa level of 0.05 which might be concluded that concentration has no significant effect on the experiment either because F value is 2.43 at Alfa level 0.05. Again, P value, 0.089, tells us that concentration is not a significant factor where Alfa is equal or less than 0.05.

F value is found to be 3.01 for number of cells too, where Alfa value is 0.05, but the F value here, 704.65, shows a significantly higher number which tells us that the number of cells is the significant factor that effects the experiment. P value that is 0.0 verifies that the number of cells is the main factor that has significant impact on the experiment.

Table 5 Factorial Design on days vs. # of cells vs. current

Factors: 3 Factor Levels: 2, 4, 4

Runs: 32 Replicates: 1

General Linear Model

Factor	Type	Levels	Values
Days	Fixed	2	12
Number of Cells	Fixed	4	1234
Concentration	Fixed	4	1234

Analysis of Variance for C7, using Adjusted SS for Tests

Source	**DF**	**Seq.SS**	**Adj SS**	**Adj MS**	**F**	**P**
Days	1	0.2433	0.2433	0.2433	1.11	0.302
Number of Cells	3	36.5690	36.5690	12.1897	55.87	0.000
Concentration	3	2.2042	2.2042	0.7347	3.37	0.035
Error	24	5.2365	5.2365	0.2182		
Total	31	44.2529				

Unusual Observations for C7

Obs	C7	Fit	StDev Fit	Residual	St Resid
1	1.41000	2.31625	0.23355	-0.90625	-2.24R
8	3.99000	3.03875	0.23355	0.95125	2.35R

R denotes an observation with a large standardized residual.

The ANOVA table is created using current as outcome of the experimentation. Again, looking at F values and P values, we can conclude that the number of cells is a significant factor because experimental F value is significantly higher than the F value obtained from the statistical tables.

4. 3 Experimental Apparatus, Design and Procedures of PEMFC Kit

A. PEMFC Educational Kit

The PEM Fuel Cell ordered from Warsitz Co. generates pure hydrogen using solar power. It has outlets of power that may be connected to a fan and a toy car. Experiments were conducted to measure voltage and current changes in fuel cell system under different conditions. The system worked as a demonstration system.

B. Experimental Procedure

Operating instructions came with the package as follows:

1. Mount the fuel cell and fan assembly to the base plate.
2. Remove the tube from the electrolyser and hook up the H_2 and O_2 tubes.
3. Hook the two lines up to the fuel cell.
4. Remove the hose connecting the H_2 and O_2 side of the electrolyser (labeled remove)
5. Plug in the fan RCA jack.
6. Set the unit in the sun; let the electrolyser purge the system and wait for the fan to start running.
7. When the fan is running strong (about 10 minutes) hook up the car.
8. The system should run all day and 15 minutes after the solar panels stop producing power.

On a cloudy day the system was put outside. After 20 minutes, bubbles came off of the tubes containing vinegar. There was not enough H_2 storage tower pushing water into the upper chamber, which was supposed to happen. There was not backpressure test tube bubbling other than water tube pushing the water into the other one. After the system sat for 45 minutes, there was a little change in the hydrogen tube that showed that half of the tube was filled with hydrogen. The fan started to spin after system purged itself. When the toy car was attached, there was no movement. Experiment was stopped because of inclement weather.

Experiment was repeated indoors, with the solar plates under bright electric lamp for three hours and system was able to fill the entire tube with hydrogen.

C. Apparatus

PEM Fuel cell was mounted on the baseboard that has Hydrogen and Oxygen inflow that is coming from the tubes that are connected to each other that are used to generate pure hydrogen with solar power.

D. Experimental Results and Discussion

After connecting all the components of the system several experimentations have been conducted. Summary of the experimentation conditions are given in Table 6.

After the car was disconnected, the fan went faster and the voltage is 0.445. When everything was turned off, the voltage went up to 0.9 and leveled off.

The tank containing $H_{2\ was}$ observed to be filling with water. System was left without the solar system and hydrogen tube was filled with water overnight.

Table 6 Experimental Results of PEM Fuel Cell Operating With Solar System

Measurements **Voltage**	**Conditions**
0.876 V	Solar system is on and Hydrogen tube is full with hydrogen.
0.0686 V	Fan is on – voltage steady.
0.06 V	Toy car stopped.
0.01 V	Both fan and toy car are on until voltage reached 0.06 and toy car stopped– rapid decrease on voltage and fan stopped at 0.01 V.
0.08 Amps	No solar system attached.
0.14 A and 0.4 V	When fan is running-no solar system is attached.

The power that was drawn from the system was very low because of insufficient fuel supply and small membrane area that the fuel cell had.

In PEMFC case, the system was able to generate power but the power was inconsistent. The results showed that with the appropriate fuel flow in the system, consistent power might be drawn. The difficulty appeared to be a lack of energy to draw pure hydrogen to be used by the fuel cell system to generate power. This mini PEM fuel cell kit showed us that the fuel cells, put together, optimally generate power that might be used in automobile applications. Working parameters should carefully be examined to have an optimal system, especially in an automobile application. Voltage needs to be regulated to have the power that is needed continuously.

It was also concluded that PEM fuel cell system test was successful. Low voltage that was drawn was probably due to hydrogen intake flow. More power generating PEM fuel cell was needed to power a prototype car.

4.4 Experimental Apparatus, Design and Procedures of PEMFC

A. Six (6) Volt and One (1) Amp PEMFC

The system includes a fuel cell stack that generates approximately 6 Volt electricity with 1 Amperage current, lecture bottle hydrogen gas tank, which had 2000-psi pressure that could be controlled with compressed gas regulator and backpressure tubes. The unit was a proton exchange membrane fuel cell that used polymer Nafion as an electrolyser that is sandwiched in between electrodes. The system was purchased from Element 1 Power Co. that manufactures demonstration system for the educational institutions at a reasonable price. The system was assembled, and experimentation was conducted to see if the fuel pressure affects the performance of the PEMFC.

B. Experimental Procedures

The instructions of assembling the system came with the apparatus. Steps are listed below.

1. Fill H_2 bottle.
2. Hook H_2 regulator to bottle, and hook Tygon tube to the left hose barb as someone is looking straight at fuel cell.
3. Fill the second test tube with three inches of water.
4. Hook the “bubbler” to the right hose barb. The water provides backpressure and keeps air from entering the fuel cell. Turn the small valve on regulator off, and main valve on. Slowly open small valve until bubbles start coming out of test tube.
5. Put the fuel cell on the forced air housing, do not turn fan on until load is applied.
6. Apply small load and turn fan on. The fan is volt fan, turning slower with a volt source. This is sufficient airflow.
7. Measure the voltage in the cell. The cell is limited to about volts at 0.25 Amps. If the voltage drops suddenly, then a membrane inside the cell has “reversed” and is electrolyzing water.

Remove the load and let the voltage stabilize, then reattach the load, lowering the current draw slightly. This will keep the cell from reversing.

C. Apparatus

The schematic diagram of the system that includes major components such as regulator, fuel cell stack, hydrogen bottle, and backpressure tubes as shown in Figure12.

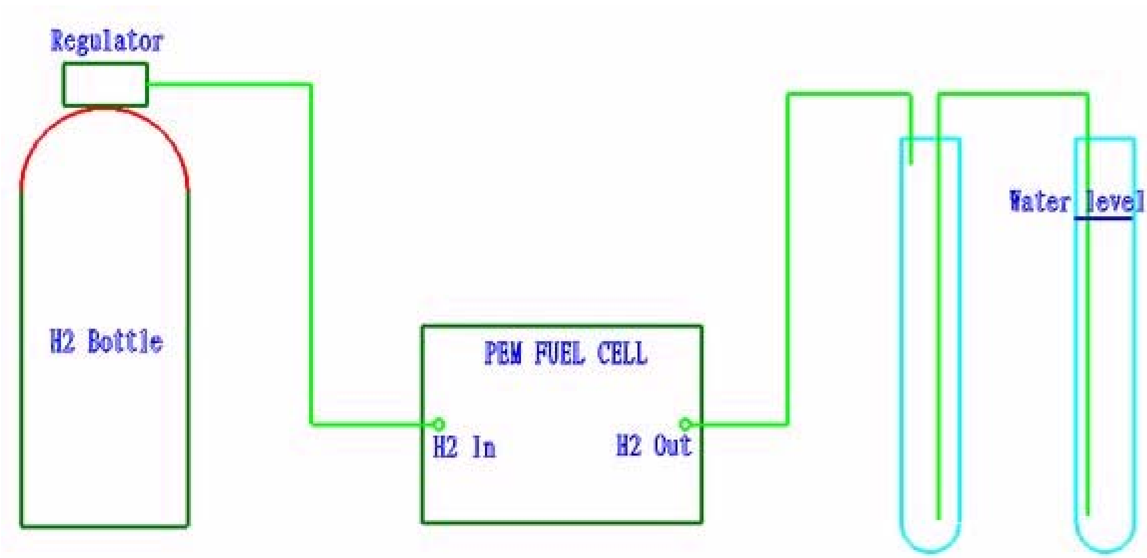


Figure 12 Schematic diagram of the PEM fuel cell system.

D. Experimental Results and Discussion

Experimentation is conducted to find out if Hydrogen concentration affects the fuel cell performance. Hydrogen bottle is filled to read 2000-psi pressure. Regulator is attached to the bottle. Fuel cell assembly is put together with backpressure tube filled with water.

Data is obtained in several different conditions without flowmeter being attached. Each condition generated different voltage and current, which is listed in Table 7. This experimentation was conducted manually because of not finding sensitive enough flow meter that might be used in this experimentation. Flow meters that might have been used in this experimentation were needed to be very sensitive and digital because of the nature of the results. The hydrogen usage of the equipment was expected to be very small and available flow meters were not sensitive enough to measure the flow of the hydrogen gas.

Table 7 Experimental data obtained in different conditions using PEM fuel cell where pure Hydrogen is the fuel source.

Hydrogen Bottle Pressure	**Conditions**	**Voltage (Volt)**	**Current (Amperage)**
1700 psi	Not fully opened hydrogen bottle valve	4.19	0.13
1600 psi	Not fully opened hydrogen bottle valve	3.13	0.52
1700 psi	Fully opened hydrogen bottle valve	4.40	0.50
1000 psi	Fully opened hydrogen bottle valve	3.20	0.50
500 psi	Fully opened hydrogen bottle valve	3.18	0.58

These results have shown that when the hydrogen bottle valve is not fully opened where there is a high pressure, 1700-psi and 1600-psi, voltage decreased from 4.19 to 3.13 volt and current changed from 0.13 to 0.52 amperage. In this experiment, it is not known how much the valve was open and how much hydrogen flows there is. As hydrogen is used, the pressure went down because of not having continuous fuel source, which will be the case in automobile application of fuel cell. When the hydrogen bottle valve is opened to the full scale, again there is a voltage decrease as the pressure decreased from 1700 to 1000 to 500 psi. The current stayed around 0.5 amperage, which exceeded the fuel cell capacity. The graphical representation of voltage vs. pressure data is shown in Figures 13 and 14, and current vs. pressure data is shown in Figures 15 and 16. As it can be seen in

Figure 13 and 14, voltage versus pressure shows an upward relationship as pressure increases and where flow of the hydrogen is controlled. Current showed a downward relationship as pressure increased.

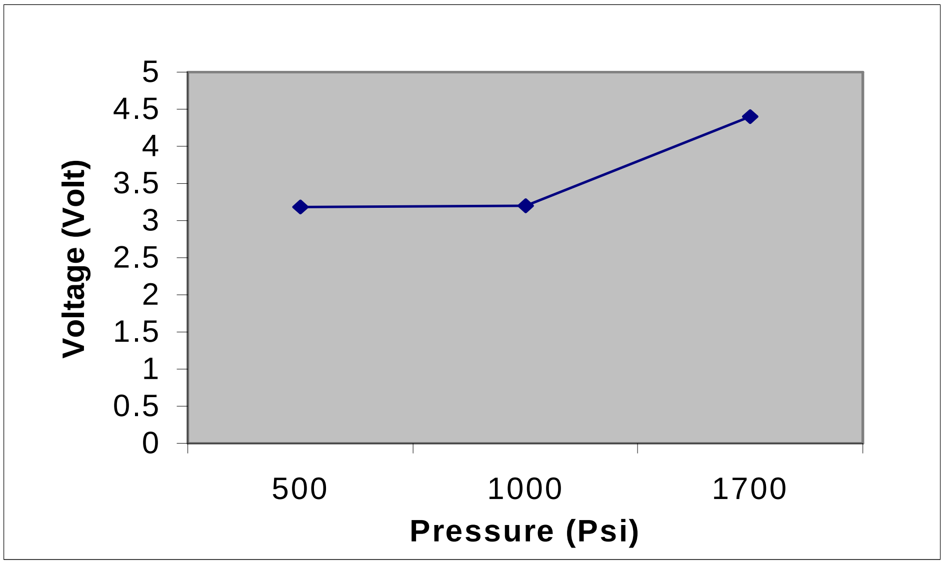


Figure 13 **Voltage vs. Pressure (Hydrogen bottle is fully open)**

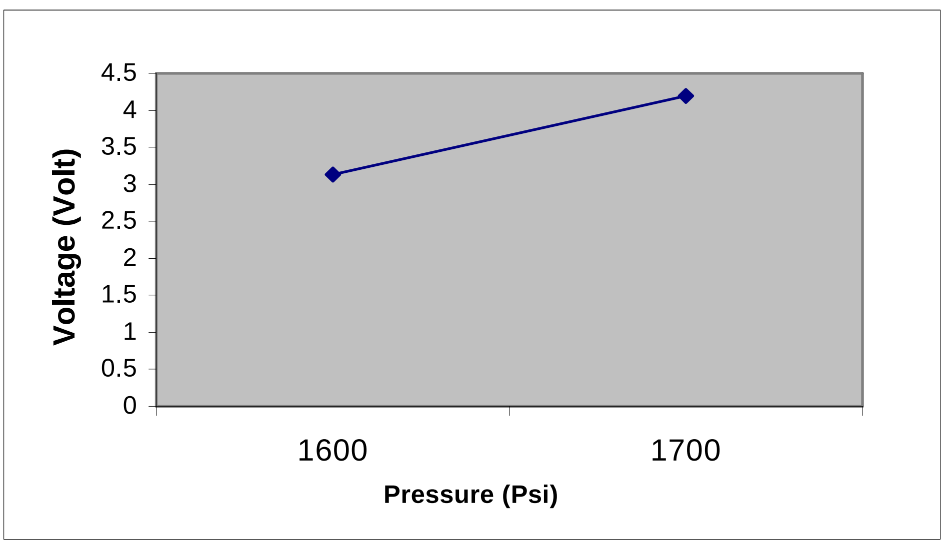


Figure 14 **Voltage vs. Pressure (Hydrogen bottle is not fully open)**

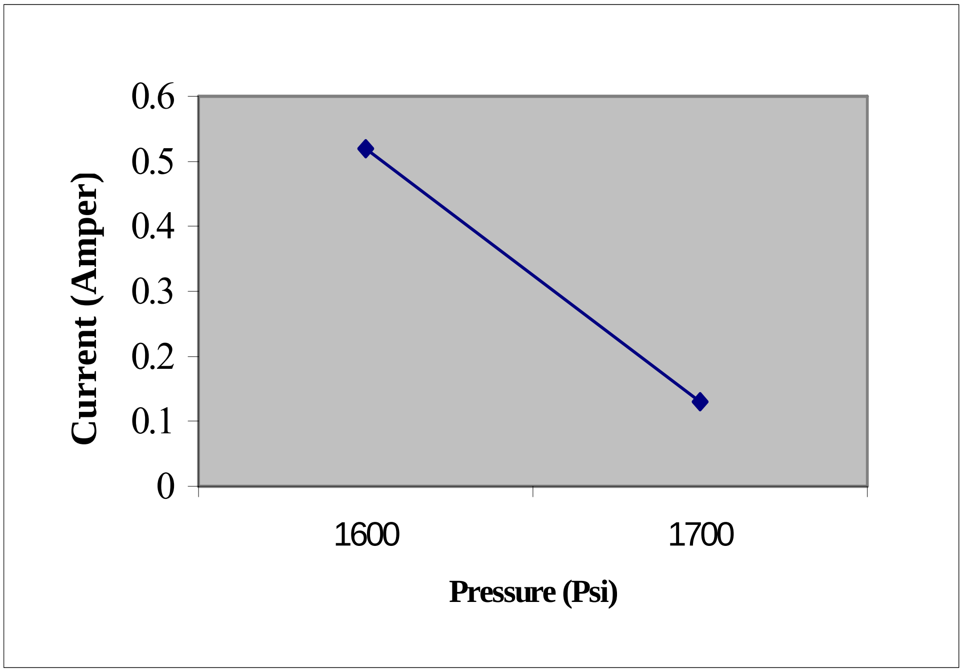


Figure 15 **Current vs. Pressure (Hydrogen bottle is not fully open)**

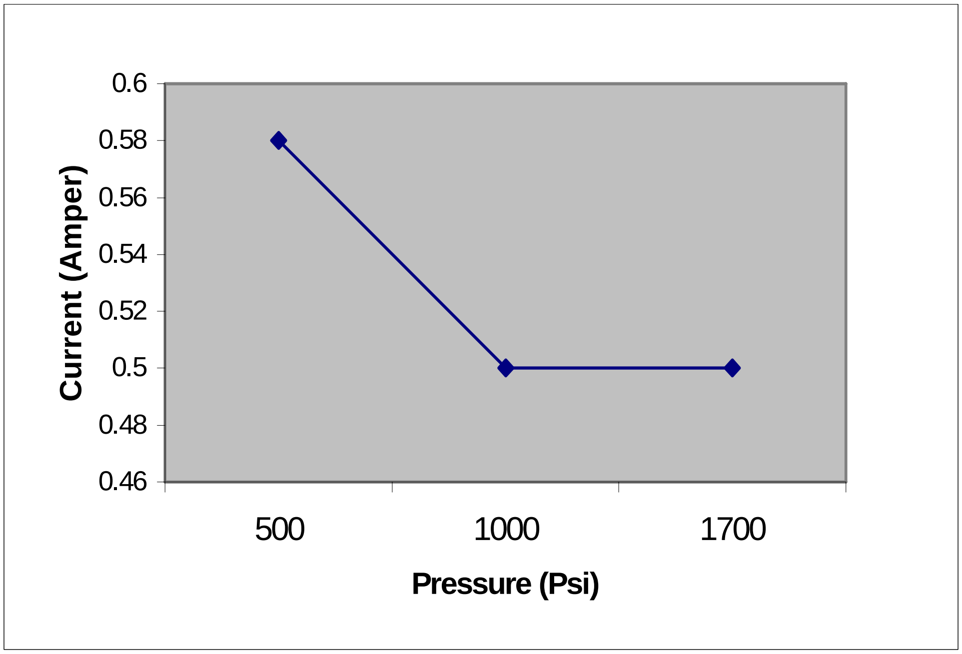


Figure 16 Current vs. Pressure (Hydrogen bottle is fully open)

4.5 Experimental Apparatus, Design and Procedures of PEM D-35 Fuel Cell Power System

The H Power Corporation Proton Exchange Membrane (PEM) Fuel Cell Power System (FCPS) that generates 12 volt and approximately 2-3 amperage current is used to power the Power Wheel toy car that is found to operate with 6 volt and 1.64-amper currency. The cigarette lighter transformer is used in between fuel cell and the car to reduce the voltage from 12 volt coming out of the fuel cell to 6 volt, what the car needed. The fuel cell is used as an alternative to lead acid battery that the toy car had already built in. There is not any alteration done to the car system and the experimentation is done on the original car that has a fuel cell as electricity source.

A. PEM D-35 Fuel Cell Power System

The major components of PEM Fuel Cell Power System are as follows:

- **Box enclosure**: contains the functional devices, which enable to FCPS to provide power
- **Fuel Cell Stack**: is the heart of the PCPS. In the stack, hydrogen is reacted electrochemically with oxygen from the air stream to form water as a by-product. In addition, a moderate amount of energy is generated. The heat that is generated must be removed
- **Microprocessor**: monitors and controls all of the activities that make FCPS work. Process values such as stack temperature, current and voltage are monitored. The microprocessor controls air pump speed, hydrogen purge, cooling fan operation and on/off requirements.
- **Air Pump**: supplies the reactant air for the fuel cell stack. It operates with DC electricity. The volume of air delivered is controlled by the microprocessor in proportion to the amount of current being delivered by the fuel cell stack. The proportional ratio is programmed at the factory and cannot be changed.

- **Cooling Fan**: is used to remove the heat that is being generated by the fuel cell stack. If the heat is not removed, the operation of the stack will become inefficient and ultimately cease. The FCPS microprocessor monitors the temperature of the fuel cell stack and turns the cooling fan on and off as is appropriate.
- **Hydrogen Inlet Solenoid Valve**: controls the flow of hydrogen to the fuel cell stack and is controlled by the system microprocessor. This valve is normally closed and has to receive power from the microprocessor to open.
- **Hydrogen Purge Solenoid Valve**: controls when hydrogen purge occurs within the system. The hydrogen passages within the fuel cell stack must be periodically purged for impurities and/or water that build up during operation. This valve is normally closed and receives power from the microprocessor in half-second bursts every few minutes to perform the necessary purging of the fuel cell stack. The amount of hydrogen released into the box enclosure of the FCPS is negligible and poses no safety issues.
- **Dual Stage Pressure Regulator:** adjusts the incoming hydrogen pressure (250 psig max) to approximately 5 psig for proper and safe stack operation.
- **Filters:** prevents airborne materials, contaminants and vapors from entering the stack. Filters are on the fuel cell stack as an activated carbon filter on the reactant air inlet.
- **Fuel Source:** supplies hydrogen to the fuel cell stacks. Hydrogen storage cylinder is mounted on the side of the unit and has 250-psig pressure. The supplied hydrogen storage system uses granulated pyrophoric metal hydride alloys allowing low-pressure storage of the hydrogen gas. The hydrogen pressure is regulated by an internal pressure regulator down to approximately 5 psig. The fuel cell system is designed for using industrial grade, or better, hydrogen at 5 psig for routine operation.

♦ **Power Connector:** allows any device to be connected to the system through 12 VDC Auto Power Receptacle. Any device drawing 35 W or under, with an auto DC Power plug will mate with this power connector.

B. Experimental Procedure

The operating procedure came with the unit from the manufacturer. Experimentation is conducted following the steps to get the unit operating and connecting it with the toy car. Steps for the operations are follows:

1. Hydrogen cylinder is connected to the fuel cell system by removing plug from the quick connect fitting on the hydrogen cylinder and sliding it through the clip then connecting the mating hydrogen inlet fitting prior to connecting to the hydrogen source fitting.
2. Hydrogen pressure greater than 250 psig will damage the internal pressure regulators of fuel cell system.
3. Turn fuel cylinder valve on by rotating valve counter clockwise.
4. Place red on/off rocker switch to the “1”position. After approximately two-three seconds the green indicator light will come on indicating the fuel cell operating. A pump hum may be noticed; this is also an indication the system is working.

NOTE: If during start-up or while system is running, an abnormal sound is heard or if the unit is not functioning properly, shut system off by placing the switch in the “0” position. Wait several seconds and retry start-up procedure. If the unit does not “turn on” the 9V battery may require replacement.

5. Connect the toy car (Power Wheel – 6 V and 1.64 Amp), using a transformer that reduces the 12 DC voltage output of the fuel cell to 6 V. The transformer is designed to pass up to 3 Amp current. Power Wheel toy car may remain connected when switching systems on and off.

6. The fuel cell power system may be shut down at any time by placing the on/off rocker switch to the "O" position and turning the valve on the hydrogen storage cylinder clockwise to close. The fuel cylinder is disconnected by depressing the quick connect release button while firmly holding the cylinder.

♦ **Guidelines for Operation:**

Operating Environment: Normal ambient conditions

Operating Temperature: 32 F to 105 F (0 C to 40 C)

Storage Environment: Normal room ambient conditions with humidity levels of 15 percent to 90 percent

Storage Temperature: 45 F to 95 F (7 C to 35 C)

Periodic Stack Conditioning: The fuel cell stack contains a special membrane that is critical for the proper operation of the fuel cell. This membrane must be kept moist. Drying out of the membrane will result in a lower power output at start up for a period of time. Once the membrane has become wet enough, the power output will recover. During long period of extensive storage, it is advised that the FCPS be started up and left running for 10-20 minutes once every two to three months to condition the membrane and ensure that is sufficiently moistened.

♦ **General rules are as follows**:

a. Avoid operating or storing the fuel cell in extremely cold environments. Freezing of the fuel cell stack can permanently damage the system
b. During operation, avoid blocking the inlet and outlet air passages on box enclosure. Proper air circulation is requires for optimum performance

c. The fuel cell system should only be connected to devices meant to operate at 12 V and rated at 35 W or less (3 amp. Max)

d. The fuel cell system should be handled with care, avoiding severe mechanical shock and vibration condition.

e. Fuel cell power system cover should not be removed as the internal auxiliary and electronic components can be easily damaged.

f. Hydrogen cylinder should be refueled according to H-Power approved procedures.

g. In order to assure the FCPS will be optimum working order, replace the 9-Volt battery once every six months.

The PEM D-35 Demo fuel cell system provides a maximum 35 watts continuous power as needed. A control loop continuously adjusts the operation of auxiliary components as current and temperature demand. Figure 18 shows the schematic diagram of PEM fuel cell apparatus.

- **Fuel Cell Temperature Control:** The operating temperature of the stack is monitored and controlled to ensure proper operation and prevent overheating of the fuel cell stack. The cooling fan used to maintain the fuel cell within specification temperature range is controlled by the system microprocessor.

- **Hydrogen Purge Timing:** As the hydrogen consumed within the fuel cell, water and other impurities accumulate until they block the flow of hydrogen. Periodically a solenoid valve is opened to allow the water and any impurities to be purged from the fuel cell stack.

- **Reactant Air Flow**: The fuel cell requires a constant stream of air to provide oxygen and remove water. The airflow rate is determined by the current output of the fuel cell and is controlled by a DC pump.

C. Apparatus

Fuel cell system that is purchased from H Power, schematically shown in Figure 17. This diagram includes all the components of the fuel cell power system including the hydrogen bottle that is a fuel source for the system. Detailed descriptions of all components are given in previous section.

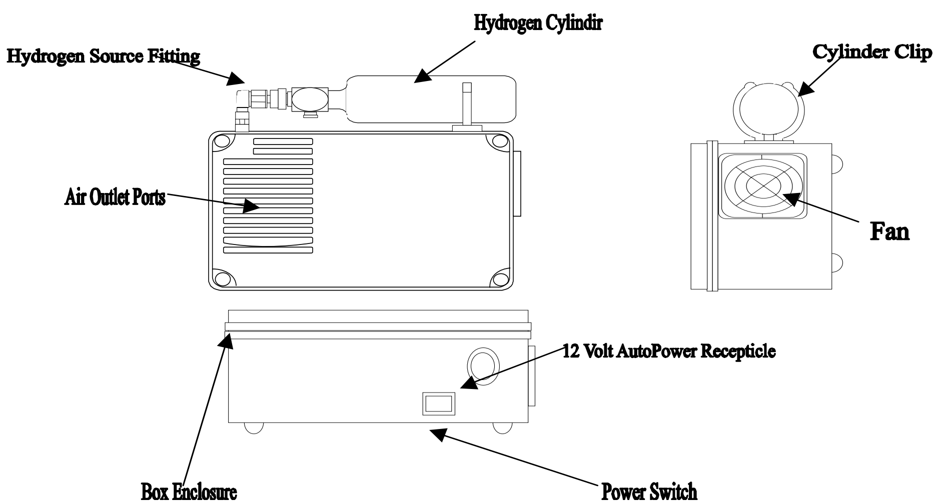


Figure 17 Schematic Diagrams of PEM Fuel Cell Apparatus

D. Design of PEM D-35 Fuel Cell Power System With a Prototype Car

Using the specification of Fuel Cell System parameters, listed in Table 8, the toy car and the fuel cell system were connected. The power that is the outcome of the fuel cell was needed to transfer from 12 Volt to 6 Volt, which is what the toy car required. Alternation of the toy car was not considered for this research and transformer was thought as a viable option.

PEM fuel cell power system has been connected to the power wheel car through a cigarette lighter connection that reduced the voltage from 12 to 6 Volts electricity from fuel cell to the car. Current stay the same, which was in between 2-3 Amperage. The lighter was then connected to the original battery's plug, which was cut off the battery. The original plug was used here. Again this was done to keep the original toy car shape, size and the operating condition. The compartment that was allocated for the battery was not large enough for the fuel cell and its accessories that fuel cell was put at the flat place where the passenger would sit and secured at that location. The hydrogen bottle was already attached to the fuel cell itself.

Table 8 Specification of The Fuel Cell System

Model:	**PEM D-35 Unit**
Product	Fuel Cell System
Designation	35-Watt Fuel Cell System
Electrical Specification	
Operating Voltage	12 V Nominal
Operating Current	2.0 A Nominal, 3.0 A Max
Power at 3.0 A	35 Watts
Connection	Through an Auto 12 DC Power Receptacle
Design Features	
Physical Dimensions (with Hydrogen Cylinder)	
Height	4.2 in.
Weight	Approximately 7.7 lb. Tested 3576.6 gr
Width/ Length	7.95 inch / 9.40 inch
Volume	314. In^3
Fuel Source	Designed for Metal Hydride Canister packaged to deliver 100 Wh of electric energy (As supplied by H Power Corp.)
On/Off indicator	Green Red Light

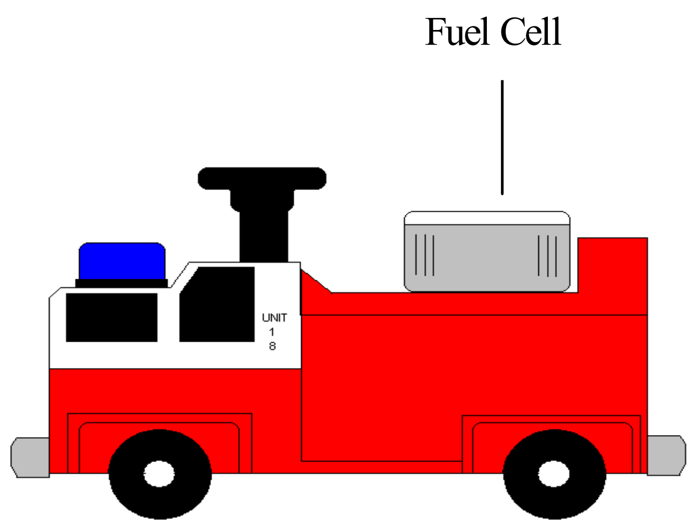


Figure 18 Schematic Diagram of Prototype Fuel Cell Operated Toy Car

The toy car was requiring 6 volt and 1.64 Amperage current to be operated by electricity. This was determined through manufacturer's instructions and testing the car in electrical engineering laboratory for the current that needed to be supplied. The electrical motor that was attached to the car was not visible and there was no information about the current. The car had a gear that could be used for forward and reversing. For the experimentation, forward gear was used because reverse gear was unoperable for the power that was provided. Two pedals were used for acceleration. Figure 18 is the schematic diagram of the system.

E. Experimental Results and Discussion

Experimentation was performed using the H Power Fuel cell that is connected to the Power Wheel Toy Car to obtain readings of the time taken to move a distance of 238.5 inches (6.0579 m). This distance was measured on the flat surface and the experimentation was performed on the flat surface. Fuel cell connection is done through voltage transformer, which is in the shape of cigarette lighter, and fuel cell itself was secured on the car. The tests were done with various weights added to the system and the results were tabulated for analysis. The weight of the complete system, including the fuel cell and hydrogen cylinder was also recorded. Calculations were performed to obtain the velocity, acceleration, force and work done by the system. Various graphs were constructed in order to compare the results and to draw conclusions.

The fuel cell system and power wheel car has been weighed. The results were:

Weight of fuel cell system (including H_2 bottle and connection accessories) = 3576.6 gr.

Power Wheel Car (with battery compartment cover): 6567.5 gr.

Power Wheel Car (without battery compartment cover): 6382.7 gr.

The distance car was being tested is 238.5 inch. (6.0579 m)

Tables 9 and 10 contain the measured readings of the load and time taken to travel the distance measured on two different days. It also includes the calculated values of the average velocity; acceleration, force and work done in addition to the log force and log work. Acceleration due to gravity was taken as $9.81 m/s^2$ for these calculations. In calculating the force, the added mass of the load on the car must be considered in order to obtain valid results.

Distance, x = **238.5 in. = 6.0579 m**

Mass of car, m **= 6.3827 kg**

Table 9 Experimental Results and Calculations of H Power PEMFC

Load, L (N)	Avg. Time, T (s)	Velocity, v (m/s)	Acceleration, a (m/s^2)	Force, F (N)	Work, W (J)	Log Force	**Log Work**
0	11.21	0.540401427	0.024103543	0.153846	0.931982	-0.8129147	-0.03059
5	11.89	0.509495374	0.021425373	0.147672	0.894582	-0.8307021	-0.04838
10	11.9	0.509067227	0.021389379	0.169227	1.025163	-0.7715292	0.010793
20	11.95	0.506937238	0.021210763	0.211057	1.278565	-0.6755993	0.106723
30	12.11	0.500239472	0.020653983	0.268679	1.627632	-0.5707659	0.211556
40	12.41	0.488146656	0.019667472	0.33604	2.035695	-0.4736094	0.308713
50	12.45	0.486578313	0.019541298	0.433483	2.625995	-0.3630282	0.419294
60	12.7	0.477	0.018779528	0.531444	3.219434	-0.2745425	0.50778

Table 10 Experimental Results and Calculations on H Power PEMFC (Experimentation is conducted on a different day)

Load (N)	**Time 1 (s)**	**Time 2 (s)**	**Time 3 (s)**	**Time 4 (s)**	**Avg. Time (s)**	**Velocity (m/s)**
0	11.3	11.49	11.16	11.4	11.348	0.5338532
5	11.3	11.61	11.27	11.8	11.495	0.5270030
10	11.7	11.56	12	11.8	11.765	0.5149086
20	11.6	11.77	11.45	11.8	11.655	0.5197683
30	11.8	12.09	11.7	12.1	11.92	0.5082130
40	11.9	12.15	12.09	12.4	12.143	0.4989005
50	11.9	12.44	12.24	12.7	12.315	0.4919123
60	12.5	13.19	12.84	13	12.875	0.4705165

Acceleration (m/s2)	**Force (N)**	**Work (J)**	**Log Force**	**Log Work**
0.023522	0.150139	0.9095326	-0.8235038	-0.04118
0.022923	0.157995	0.9571185	-0.8013563	-0.01903
0.021883	0.173133	1.0488249	-0.7616190	0.020703
0.022298	0.221876	1.3441076	-0.6538880	0.128434
0.021317	0.277312	1.6799331	-0.5570301	0.225291
0.020543	0.351008	2.1263757	-0.4546820	0.327640
0.019972	0.443038	2.6838842	-0.3535583	0.428763
0.018272	0.517095	3.1325105	-0.2864295	0.495892

Calculations were done using the formulations below:

Velocity**: change in distance divided by change in time.**

$$\mathbf{v = (d\,x / d\,t)}$$

$$= (6.0579 / 11.9)$$

$$= \underline{0.509 \text{ m/s}}$$

Acceleration: squared velocity divided by the two times distance.

$$\mathbf{a = (v^2 / 2\,x)}$$

$$= ((0.509)^2 / (2\,(6.0579))$$

$$= \underline{0.0214 \text{ m/s}^2}$$

Force: mass multiplied by acceleration

$$\mathbf{F = ma}$$

$$= \{(6.3827 + (10/9.8)\} / 0.0214$$

$$= \underline{0.169 \text{ N}}$$

Note: The mass of the load added must be considered in the calculation.

Work Done: Force multiplied by the distance traveled

$$\mathbf{W = F.\,x}$$

$$= (0.169)(6.0579)$$

$$= \underline{1.03 \text{ J}}$$

There are several important factors that have to be considered when completing the calculations. For example, the load added to the car also adds to the total mass of the system. This fact is important, as its omission would cause significant error in the force and all subsequent calculations.

The experiment was repeated under the same conditions, which was a flat distance of 6.0579 m. and four additional data are obtained for each case of additional weight being added onto the car.

ANOVA table (Table 12) is prepared to analyze the experimentation. Acceleration data is used and the unit of acceleration is taken as cm/s^2 because that time measurement did not have significant differences in the numerical values. Five time data have been taken into consideration to calculate the acceleration (Table 11) and the resulting data has been taken to calculate ANOVA table. Acceleration data is as following in cm/s^2.

Table 11. Calculation of acceleration data in cm/s^2

Load (N)	Time 1 (s)	Time 2 (s)	Time 3 (s)	Time 4 (s)	Time 5 (s)	Avg. time (s)	Velocity (cm/s)	Acceleration (cm/s^2)
0	11.3	11.49	11.16	11.4	11.21	14.15	42.81201413	1.512792019
5	11.34	11.61	11.27	11.8	11.89	14.4675	41.87247278	1.447121921
10	11.72	11.56	12	11.8	11.9	14.74	41.09837178	1.394110305
20	11.63	11.77	11.45	11.8	11.95	14.6425	41.37203346	1.412738039
30	11.84	12.09	11.7	12.1	12.11	14.9475	40.52784747	1.355673105
40	11.93	12.15	12.09	12.4	12.41	15.245	39.73696294	1.303278548
50	11.92	12.44	12.24	12.7	12.45	15.4275	39.26689353	1.272626593
60	12.48	13.19	12.84	13	12.7	16.05	37.74392523	1.175823216

Table 12 One-way Analysis of Variance: Load vs. Acceleration

Analysis of Variance (ANOVA)					
Source	DF	SS	MS	F	P
Factor	1	2604	2604	10.89	0.005
Error	14	3347	239		
Total	15	5951			

ANOVA table shows that F value for the factor that is added load is 10.89. Where Alfa is 0.01 F value found to be 8.86 which is less than what we have for the experiment which suggests that we conclude that the factor, added load, has a significant effect on the experiment and P value which is 0.005 tells us that the data we gathered shows that load is the significant factor of the experimentation. We can conclude that the load that is being added on to the car has direct effect on the time that takes the car to travel known distance which translates to acceleration of the car, work done by the car, and force generated. From the data that was gathered we can tell at the level of 20 N loads, the acceleration does increase even though the load increased then it decreases again. This may be due to the experimentation error.

Depending on how much acceleration may be needed, the best load level can be found for the car. With the prototype we can achieve 60 N maximum load levels with decreasing acceleration.

Graphical illustrations were prepared to see if there is any change to the trend received the first time, which was performed on a different day with different operators. The graphics were plotted out using the data calculated for velocity, acceleration, force, work, and log force and log work to see the trend since the graphs gave us parabolic lines for force and work.

Figure 19 shows velocity changes as load added on to the car that indicated that as the car gets loaded with additional weights, velocity decreases. Velocity went from 0.54 to 0.47 m/s as load was increased on the car. After 60 Newton additional weight on the car and fuel cell system (60 kg where $g = 9.81\ m/s^2$), the toy car did not move and needed additional time to recover and start again. The trend was almost linear and had a negative direction.

Figure 20 shows acceleration changes as load added on to the car, which shows similar velocity characteristics because acceleration is simply squared velocity divided by two times the distance, which is constant. Where there was no load on the car other that the fuel cell itself, acceleration was 0.024-m/ s^2. It decreased to 0.018 by the time there was 60 N added weights on the car.

Figure 21 shows the relationship between force changes as load was added. This relationship graphically shows exponential relationship, as the weight increases, force increases too. To see it clearly, Figure 23 is constructed where log force is illustrated against load added which showed that the log of the force in base 10 is proportional to the load added to the car. It is observed that the first reading was off and deviated from the rest of the data.

Figure 22 shows work charges with increasing load.

These graphics represent the forward driving on a flat surface. We were not able to get the car to reverse. Tremendous effort was used to keep the car manually moving in a straight line since there was not a driver who could keep the wheel straight. Turning, lane changing, slowing down, usage of car accessories, and other characteristics. That might use electricity have not been considered in the experiment.

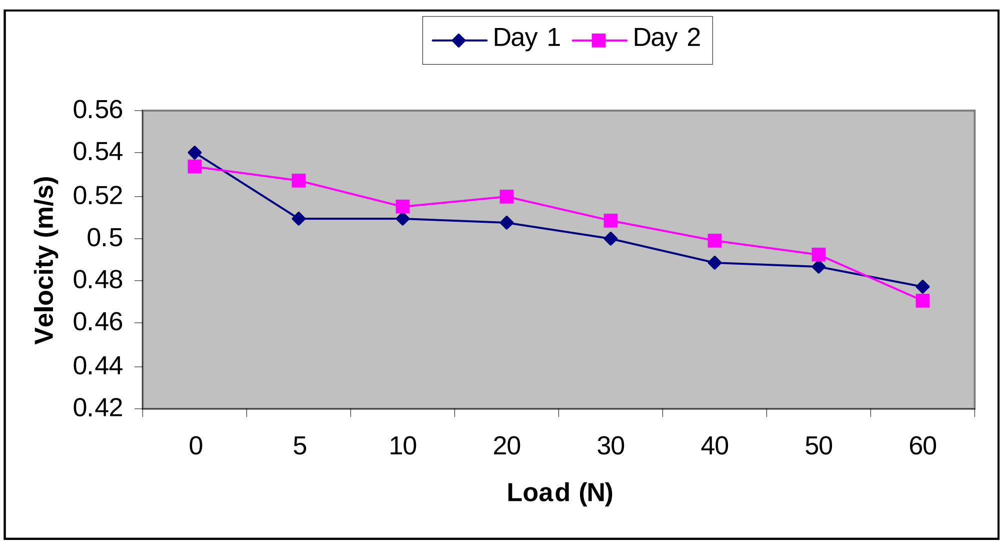


Figure 19 Velocity Changes As Load Added

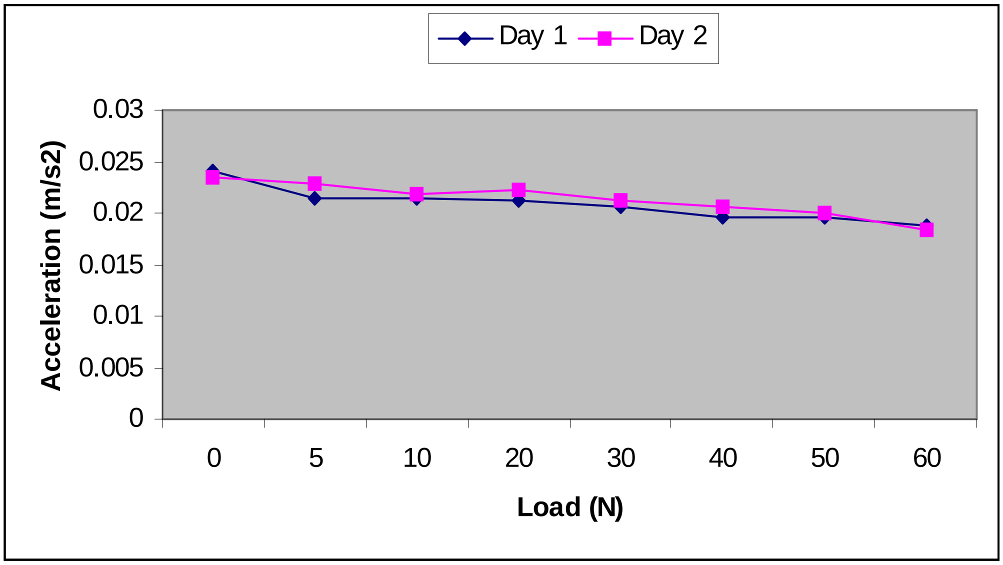


Figure 20 Acceleration Changes a Load Added

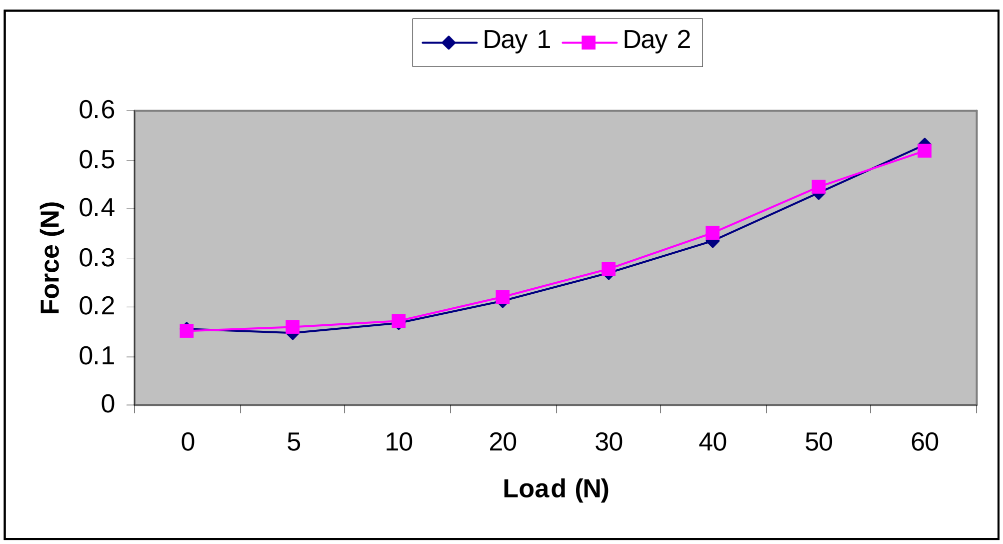


Figure 21 Force Changes a Load Added

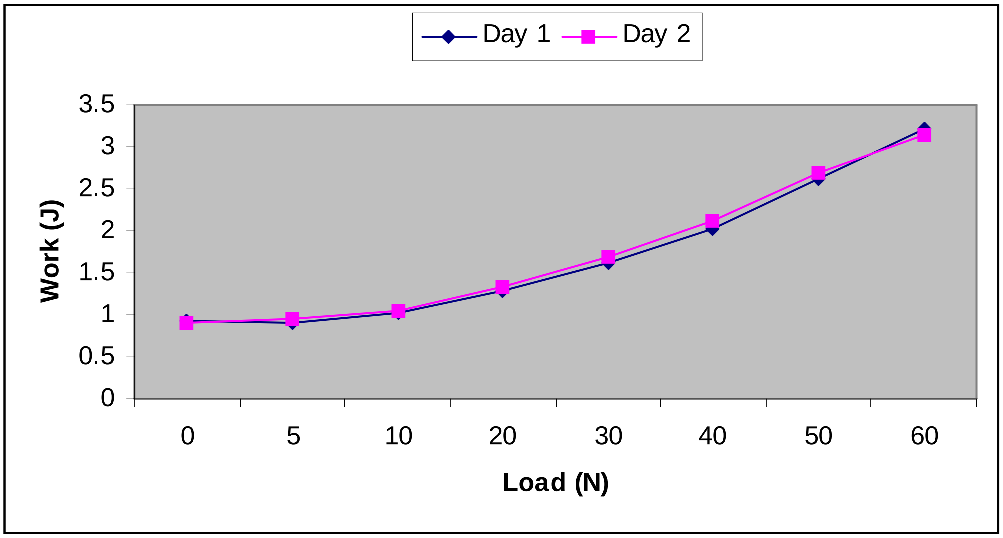


Figure 22 Work Changes As Load Added

Figures 21 and 22 show that the relationship is not linear between the force and load, and work and load. To see the relationship more clearly, Figures 23 and 24 have been developed where log force and log work are illustrated against load added.

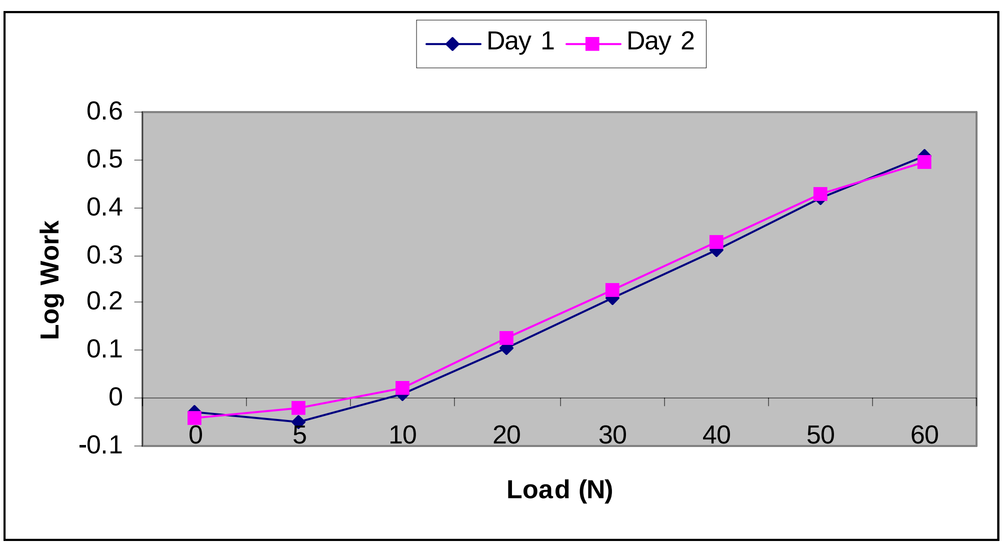


Figure 23 Log Work Changes as Load Added

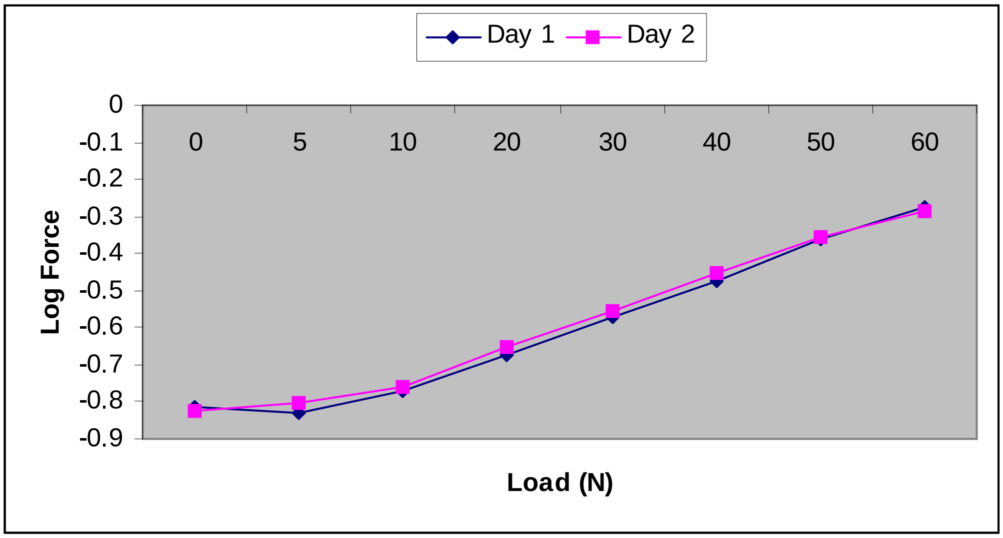


Figure 24 Log Force Changes As Load Added

Experimentation was repeated on the slope, which was not steep (approximately 30 degrees), but no usable data could be obtained because the car did not have velocity for going up the slope. Also the reverse gear did not generate any usable data. The prototype could only generate 9.84-watt power theoretically and the weight of the car and the fuel cell system was large.

As it can be seen from these results, the first set of data compares with the second set of data that was obtained on a different day. Trends are similar and the conclusions may be stated the similar way.

Fuel cells, which are generating electricity 6 V, and current approximately 2-3 Amperage might be used to power the toy car that uses 6 V and 1.64 amperage to operate. Fuel Cell is generating continuous power, which might be used in automobile application. Fuel cells can be an alternative to batteries. To get the prototype car operating which would theoretically operate with

9.84 Watt power (6 volt x 1.64 amperage), the fuel cell system, power wheel toy car, transformer, and connection wires were purchased and used in the final prototype. These were listed as follows:

Fuel Cell (including Hydrogen Bottle): $2155

Connection Equipment (transformer): $18

Power Wheel Toy Car: $89

Total Cost: $2262 per 9.84 Watt.

This cost translates to $ 229.878 per watt.

Because of the limited Fuel Cell supplier and the fact that these fuel cells are being manufactured on an order base, the laboratory was limited to what was available in the market considering the time limit. This was one of the reasons that the researchers bought 12-Volt fuel cell and transformed it that to 6 Volt. The equipment that was obtained was sufficient to power a toy car, which required approximately 10-Watt power.

SECTION 5

5.1 EXPERIMENTAL APPARATUS, DESIGN AND PROCEDURES OF PEMFC (PROTOTYPE II)

The objective of this research is to build a more efficient prototype with a higher power motor that enables us to utilize the full power Proton Exchange Fuel Cell (PEM). The distance was measured and the prototype car was operated through that distance. The time that it took the car to travel is recorded. Using the time data and formulations, acceleration of the car, force and work are calculated to see if a higher power motor made any difference in performance of the prototype.

In the original prototype of fuel cell application in an automobile, the application of full power fuel cell was not attempted to be utilized because of limitation of the motor. Even though the outcome of the research was not affected by this limitation, the calculation of the price per watt was. The general statement of fuel cell being expensive still holds true even if the full power of the PEM fuel cell was used here.

To maximize the power usage, the prototype II was designed with a higher powered motor that operated on 9-12 DC V and max 1.98 Amperage currency. The RPM specified on the motor was 18,000 RPM (with load). The speed (no-load) was specified as 24,000 RPM. The second prototype was also radio controlled R/C) to eliminate hands on steering that interferes with the experimentation. A two-channel digital proportional R/C system was used to control prototype II. The transmitter carries 12 V of power and a current drain of 250 mA. This portion of the prototype is powered with the AA-batteries. Four batteries for the car and eight batteries for the remote control system were used. A cart was built and attached to prototype to carry the fuel cell system in the back of the car. The attachment was made with a string that allows turning smoothly and preventing high impact of the cart on to the car in case of sudden stop.

The H Power Corporation Proton Exchange Membrane (PEM) Fuel Cell Power System (FCPS) that could generate 12 volt and approximately 2-3 Amperage current was used to power the King Blackfoot Toy Car. The car originally operated with a lead acid battery and the motor of the car drew 7.2 Volt and 0.7 amperage currencies. This motor was replaced by a motor that generates more power. Theoretically, the prototype II uses 22.8 Watt power (12 V x 1.9 A) compared to prototype I, which was 9.84 Watt. The distance that was used was measured as 623 inches.

A. PEM D-35 Fuel Cell Power System

The major components of PEM Fuel Cell Power System were shown in the section of 4.5 in this document as Figure 17 (page 55). The same fuel cell system that was purchased from H Power corporation is used to design the prototype II.

B. Design of PEM D-35 Fuel Cell Power System With a Prototype II

Table 8 (page 56 of this document) in section 4 shows the design features of the PEM Fuel Cell. Using the specification of Fuel Cell System parameters, the toy car and the fuel cell system were connected. PEM fuel cell power system has been connected to the King Blackfoot Pick-up Truck through a cigarette lighter connection. The schematic diagram of the prototype assembly of PEM Fuel Cell and toy car is shown in Figure 25.

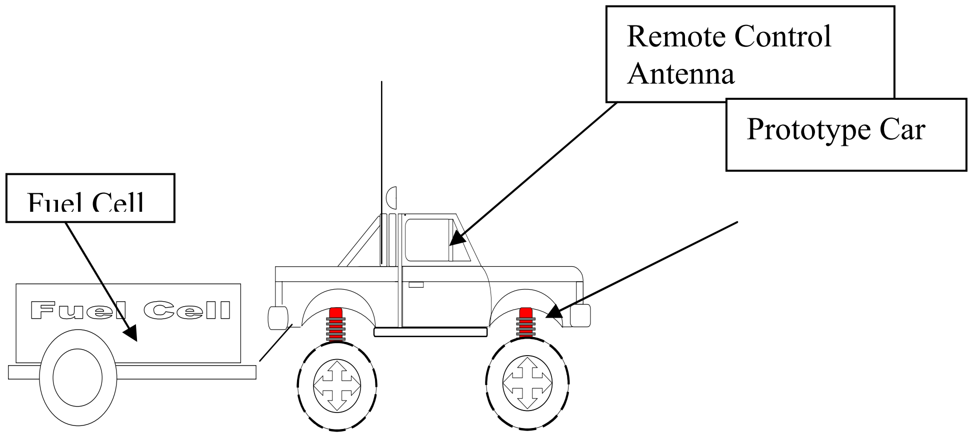


Figure 25 Prototype assemblies of PEM Fuel Cell and a Toy Car

The hydrogen bottle was already attached to the fuel cell itself as a fuel source. The Fuel cell was located on the carriage that was built with wood and the attachment to the car was flexible to make turns. The Fuel Cell was secured on the carriage using strings and tapes.

The PEM D-35 Fuel Cell System provided a maximum power of 35 Watts continuously as needed. A control loop continuously adjusts the operation of auxiliary components as current and temperature demand. The car had a gear that could be used for forward and reversing. Radio control is used for determining acceleration and direction of the car.

Using Torque Measurement Device, shown in Figure 26, the torque of the motor was measured which was 9.5 lb-inch. This measurement could be taken on the motor itself only because the measurement device required the motor to be stabilized and no gear system effect was considered. Also, the measurement was the first, highest number that was read on the gage because the reading went down so quickly.

The torque of the car is measured on the arm of the tire. The motor power activated only back axle and one arm of the car. The arm that was picked was the arm that was being activated by the motor. The measurement of the torque on the arm was 0.95 lb-inch.

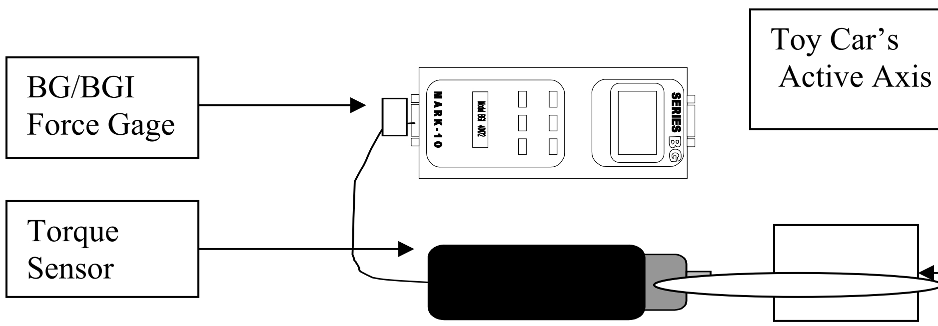


Figure 26 Torque Measurement Device (BG/BGI Force Gage / Torque sensor)

C. Design of the Experiment

Experimentation was conducted to find the time that takes the prototype to go from one point to the other one. The distance between the points was measured to be 623 inches (623 x 2.54 = 1582.42 cm.=15.8242 meter). The weight of the prototype was measured as 5667.8 gram (5.6678 kg) including the carriage that carries the fuel cell. The calculation was summarized below to find the velocity, acceleration, force, and work.

Calculations were performed using the following formulations.

Velocity: change in distance divided by change in time.

v = (d x / d t)

= (15.8242/ 11.44)

$= 1.38$ <u>m/s</u>

Acceleration: squared velocity divided by the two times distance.

$$\mathbf{a = (v^2 / 2\,x)}$$

$= ((1.38)^2 / (2\,(15.8242)$

$= \underline{0.060\ m/s^2}$

Force: mass multiplied by acceleration

$$\mathbf{F = ma}$$

$= \{(5.6678 + (10/9.8)\}\ (0.060)$

$= 0\ .40129$ N

Note: The mass of the load added must be considered in the calculation. Where the added load is 10 Newton, the mass is calculated as (5.6678+(10/9.8)) kg.

Work Done: Force multiplied by the distance traveled

$$\mathbf{W = F.\ x}$$

$= (96.164)(15.8242)$

$= 6.35$ J

There was an important factor that had to be considered when completing the calculations for force. Mass of the system was calculated as the sum of prototypes mass and the load added on to the system. This fact was important, as its omission would cause significant error in the force and all subsequent calculations, so load mass was added to the mass of the prototype.

D. Experimental Procedure of the Prototype Fuel Cell Application

Experimentation is conducted following the steps outlined below:

1. Hydrogen cylinder is connected to the fuel cell system.
2. Fuel cell is located on to the carriage and secured.

3. Fuel cell is attached to the motor.
4. Turn fuel cylinder valve on by rotating valve counter clockwise.
5. Place red on/off rocker switch to the “1”position.
6. Place start switch to forward to activate the motor.
7. Turn the radio switch on.
8. Using the remote control let the car go forward.
9. Record time to take the car travel certain distance.
10. Repeat step six through eight with added load until the car does not move.

The fuel cell power system could be shut down at any time by placing the on/off rocker switch to the “O” position and turning the valve on the hydrogen storage cylinder clockwise to close.

5.2 The Experimental Results and Analysis

The experimentation was conducted using 623 inches distance for the prototype to travel. The first experiment was conducted without any additional load, which took 11.44 seconds. The experiment was repeated twice and the average time was recorded. The second experimentation was conducted as adding 10 Newton load on to fuel cell portion of the design and the time was recorded as 17.04 seconds. The third experimentation was conducted by adding 20 Newton load but not completed due to the stop of the prototype. At this point small movements were observed, the fan of the fuel cell started working and there was smoke coming out of the motor that indicated that the load was more than the motor could handle. Experimentation was stopped at this point.

The calculations were done to find the velocity, acceleration, force and work. The graphs were not prepared to see the trend visually because the data that was obtained could only generate straight lines. At least three data points were needed to see the shape of the curve. Table 13 shows the results of calculations for the first experimentation.

Table 13. Experimentation Results for the Motor of 12 V and 1.4 Amperage

Load (N)	**Time1 (s)**	**Time 2 (s)**	**Avg. Time (s)**	**Velocity (cm/s)**	**Acceleration (cm/s2)**	**Force (N)**	**Work (J)**
0	11.14	11.74	11.44	138.3234266	6.045604308	0.342652761	5.42220582
10	15.7	18.38	17.04	92.86502347	2.724912661	0.1544426	2.443930587

The first experimentation did not generate enough data that may be used to construct a graphical representation. The repeat experimentation was conducted with the same motor on a different day. The results of the experimentation for second set with 12 Volt and maximum 1.4 Amperage is shown in Table 14.

Table 14. Experimentation Results on the Motor of 12 Volt and 1.4 Amperage Currencies.

Load (N)	Time1 (s)	Time 2 (s)	Avg. t	Velocity (cm/s)	Acceleration (cm/s2)	Force (N)	Work (J)
0	16.3	16.49	16.395	96.51845075	2.943533112	0.16683357	2.640007774
5	21.94	21.94	21.94	72.12488605	1.643684732	0.093160763	1.47419455
10	24.87	25.14	25.005	63.28414317	1.265429777	0.071722029	1.13494373
15	29.18	29.48	29.33	53.9522673	0.919745436	0.052129332	0.824904973

The third set of experiments was conducted using 12 Volt 1.9 Amperage currencies to compare the results between the two different motors. Table 15 includes the results of the experimentation conducted in this case. Figures 27, 27, 29, and 30 are constructed from the data.

Table 15. Experimentation Results on the Motor of 12 Volt and 1.9 Amperage Currencies

Load (N)	**Time (s)**	**Time (s)**	**Avg. Time (s)**	**Velocity (cm/s)**	**Acceleration (cm/s2)**	**Force (Newton)**	**Work (Joule)**
0	12.38	11.88	11.16	11.44	11.21	12.13	130.4550701
5	12.82	14.12	11.27	11.76	11.89	13.47	117.4773571

10	14.78	17.07	15.925	99.36703297	3.119844049	15.925	99.36703297
15	20.11	22.99	21.55	73.43016241	1.703716065	21.55	73.43016241

Graphical representation shows a downward relationship between the calculated velocity, acceleration, force and work as the load on the car increases in both cases. The figures for the motor that drew 12 Volt and 1.4 Amperage from the fuel cell system generated less power than the one that drew 12 V and 1.9 Amperage.

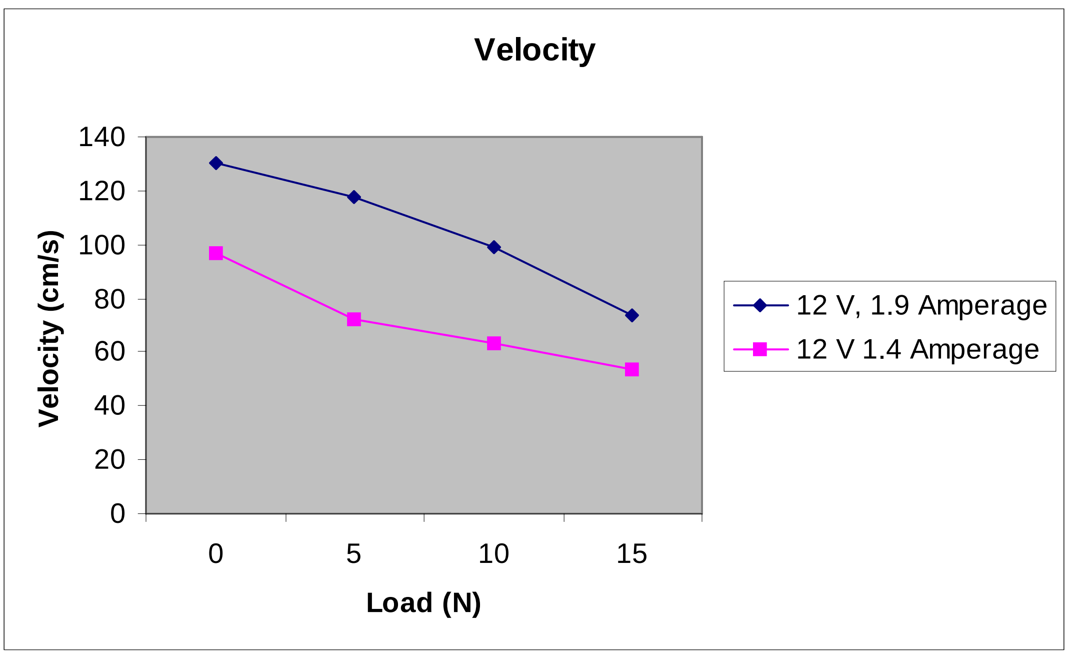


Figure 27 Velocities versus Load for Different Motors

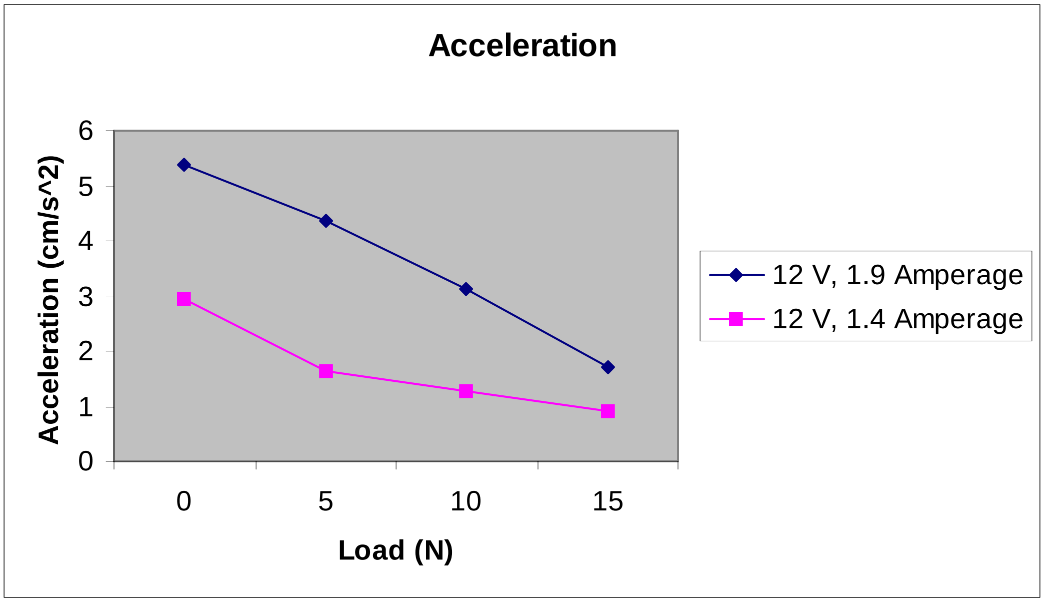


Figure 28 Acceleration versus Load for Different Motors

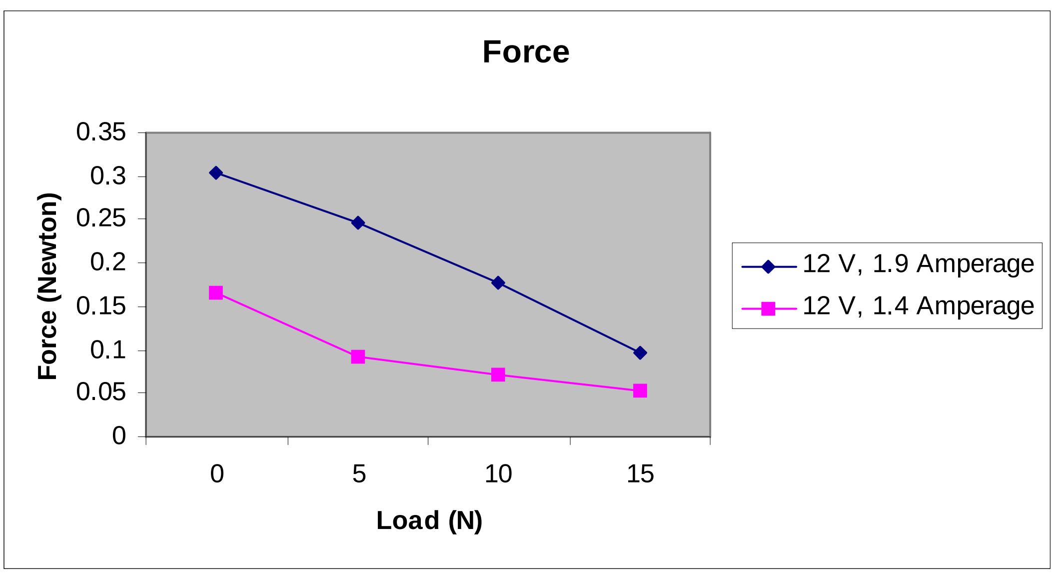


Figure 29 Forces versus Load for Different Motors

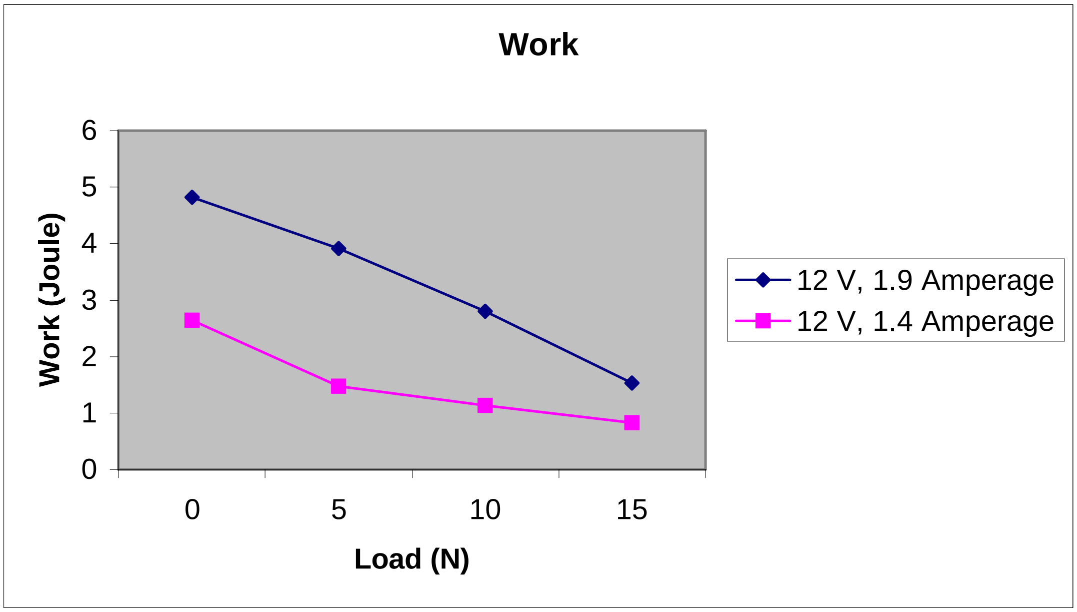


Figure 30 Work versus Load for Different Motors

From the Figures 27, 28, 29, and 30, with additional load, performance of the prototype decreases. Figures show that higher-powered motors which operate with 12 Volt and 1.9 Amperage currency produce higher performance than 12 Volt, 1.4 Amperage currency. The original motor has been replaced with these motors to use the highest possible power that fuel cell generates. Originally, we assumed the motor that has a higher intake could generate higher power. This was proven by using two different motors that was used different levels of intake power. The more power the motor took in as a source, the higher the generated power by the motor.

The motor that was rated at 12 Volt and 1.4 Amperage generated less velocity, acceleration, force and work than the higher rated motor. As load increased, the graphs showed that the variables leveled off. At the level of 20 Newton additional loads, all three variables could not be measured because the system was not generating velocity at all. The motor showed a sign of overload by smoking.

The motor rated at 12 Volt and 1.9 Amperage generated velocity, acceleration, force and work higher than that of the lower rated motor. As added load increased, the graph showed the straight line moving downward. At the level of 20 Newton added load, the system could not finish the measured distance. The motor showed a sign of overheat but there was no smoke.

After experimenting with these two motors, it is believed that the better rated the motor, the higher the performance one might get from fuel cell output. In automobile application of the fuel cell, fuel cells should be compatible with the electrical motor that is used. The gear system, and the motor itself, have a significant effect on the experiment.

SECTION 6

6.1 Design of Mini Prototype Car System

The Prototype Car System is a vehicle originally designed to run in competition with other Car Systems. The system was in an incomplete state and missing several components in several groups such as breaking system, acceleration system, steering system, motor system and the axle system. The objective of this project was to determine the missing parts, identify the parts that needed to be purchased, identify the suppliers of those parts, and design the Prototype Car System to working condition.

Most of the repairs made on the Prototype Car System were done using leftover laboratory equipment and discarded materials. All tools and laboratory equipments were fully utilized for this work.

The project is performed to get the Prototype Car System in a working condition so that fuel cells could be applied to it. Available fuel cells could only be applied as a hybrid to the combustion motor. Final Mini Baja System is shown in Figure 31 along with its specification in Table 16.

After the parts were purchased, the project became an assembly project that required some ingenuity. The participants in this project are: Jerry D McLeaurin, Inside Coordinator: Larry Summerville, location and transportation, Edikan Bassey, assembly assistant, and Andy Flambert test driver of the Prototype Car System. This fantastic crew aided in the propulsion process of the Prototype Car System.

Major parts are frame, steering section, power train part with chain, and wheels. Based on the design, all parts are carefully arranged for testing.

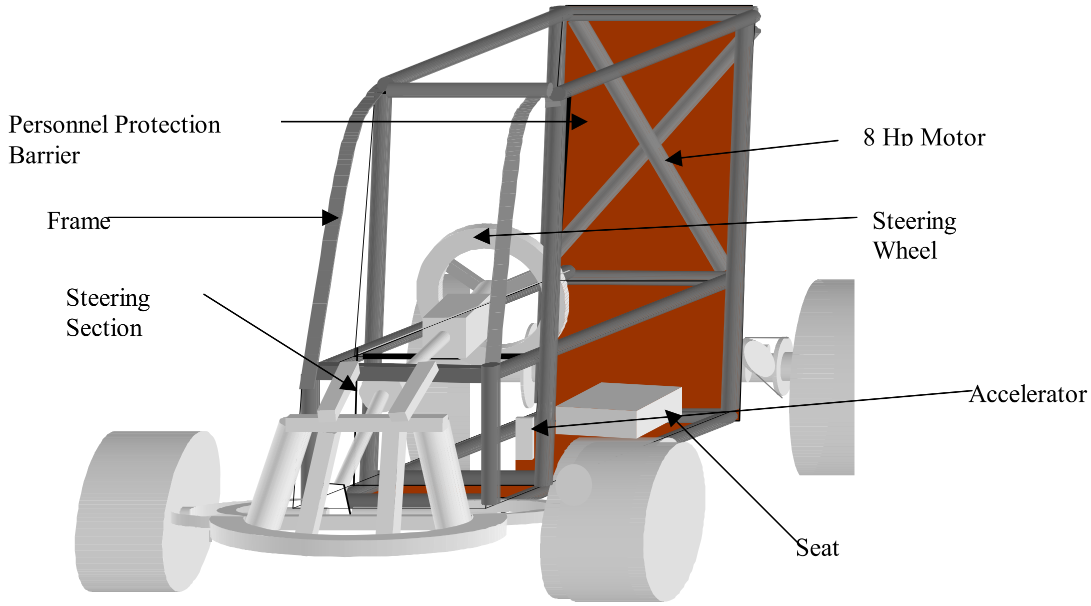


Figure 31 Schematic Diagram of the Prototype Car System.

The dimensions of the Prototype Car System are listed in the Table 1.

Table 16 Dimensions of the Prototype Car System

Description	**Dimension**
Rear wheels (from its outer limits)	99cm
Rear Width of the frame	82cm
Steering wheel to rear frame	62cm
From the center of the steering wheel to the base	53cm
Height of the Mini Baja from the floor to the base	28cm
From the Base of the Mini Baja to the highest limit	120cm
The entire length of the Frame	117cm

The outer limit of the front wheels	96cm
The Front width of the frame	44.5cm
The Accelerator / Break pedals to rear of the frame	104 cm
The entire length of the Mini Baja	254cm

The component of the system are discussed in detail in following:

1. The Steering System:

First, the steering column comprised of connecter bearings and an adjustable load that allowed the steering wheel to be positioned to suit the needs of the operator. The function of the mechanism is to steer the wheels using fasteners, rods and bolts. This system needed bearings to complete the set and give force to the vector. Because the bearings that would fit into the system were unavailable, a set of bearings had to be manufactured using regular round head nuts. The bolts had to be grinned into balls to fit the bearing that would give the Prototype Car System steering capability.

Secondly, after assembly of the steering configuration, the steering column was lowered from it original location.

2. The Motor System:

This 8 Hp motor is the primary source of power needed to activate the forward motion of the Prototype Car System. This powerful motor sends centrifugal forces to the clutch attached to the upper chain that transferred those forces to the rear axel. The problem with this motor was the missing gas tank; acceleration cable, a clutch and a chain, without those parts, the Prototype Car System would remain motionless.

The gas tank is purchased from the lawn mower shop. The frame was redesigned to get the gas tank stabilized. In the assembly of the gas tank to the motor a part of the frame had to be cut so that the tank could fit properly.

3. The Acceleration System:

This system requires a cable and a pulley to adjust the rpms of the motor. This part of the motor controls the speed of the Prototype Car System. The accelerator was incomplete missing a cable and some spring attachments. A spring attachment was put in to position to allow the accelerator to return to its normal or neutral position. The complete system is shown in Figure 32.

3.1 The Clutch System: The clutch system is identified as a centrifuge; a centrifuge is a mechanical system that rotates freely at a low rpm and as the rpm increase the plates inside the clutch expand and produce Kinetic static friction that in turn rotates the outer portion of the clutch increasing the rotational force on the upper chain. The clutch was also purchased at the lawn mower shop. It works as a centrifuge, when the motor arm rotates. The rotation per minute at the arm dictates when the clutch would engage the motor arm. The clutch would disengage when the motor reduces its rotation per minute (rpms) and goes to a neutral position.

3.2 The Chain: The 10 foot chain function is to transfer power from the motor to the rear axel producing the forward motion. A chain was purchased because the old one was dysfunctional. Before purchasing the new chain some calculated measurements had to be implemented in order to get the right pitch and length of the chain. To prevent snapping, the alignment had to be made to get the chain in line with the clutch. The test drive was conducted even though the chain was not tight to its requirements.

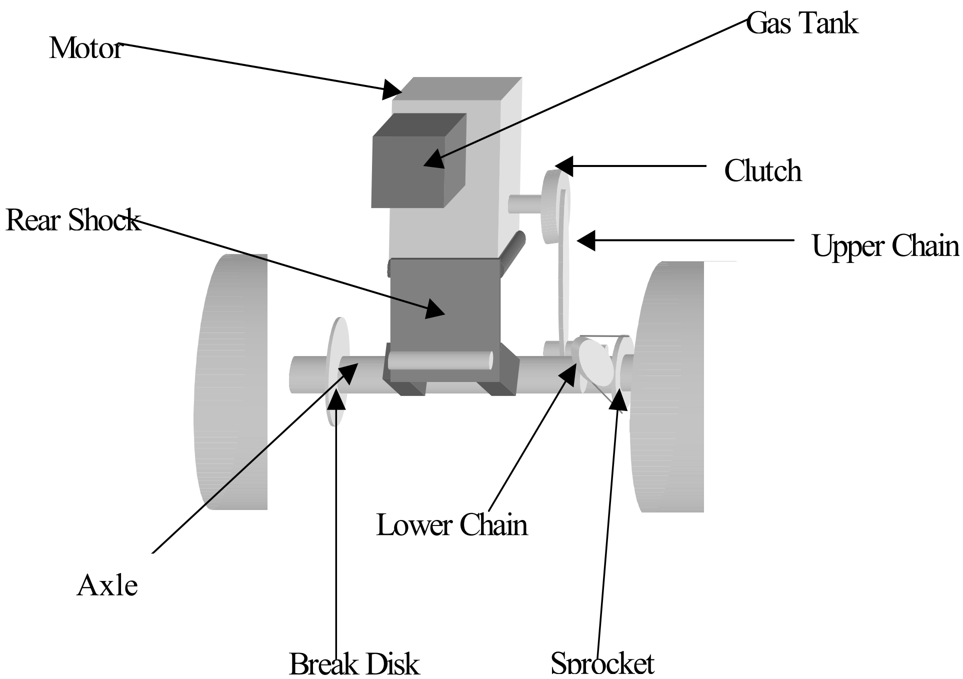


Figure 32 Schematic Design of the Rear Configuration

3.3 The motor: In order to fix the centrifuge the motor had to be elevated to tighten the chain, in doing this the centrifugal clutch should remain in uniform circular motion.

6.2 The Experimentation of the Mini Prototype Car System

The Prototype Car System was taken to the schoolyard that is approximately 150 meters long back and forth. In testing the Prototype Car System in the yard of the Michael building, researchers noticed that the clutch was turning red from the heat produced by the centrifuge. The centrifuge is the force within the clutch that's produced by the increase of rpm with respect to the motor. Because the chain that was connected to the clutch was loose, the inertia of the centrifuge was thrown off. In order for the clutch to be effective, the inertia frame must be in constant uniform circular motion.

6.3 Ongoing/Future Improvements

While completing the test run, an observation revealed that the motor was vibrating very hard. An attempt was made to reduce the vibration that caused screws and bolts to disengage. To solve this particular problem, a wooden board was placed to dampen the vibration effects of the motor. The elevation of the motor is an additional key to reducing that vibration effect.

The System shown in Figures 31 and 32 represent the Prototype Mini Car with the improvements that were made already. Future plans include the changing of the bent frame, the conversion of the steering mechanism, safety devices and an electric starter where fuel cell might be the source.

In the future, a new motor would be developed using the combination of gas and electric as a propulsion source. The Prototype Mini Car is just one type of motor system configuration and within the motor sports world there are many different environments that demand more sophisticated configurations the possibilities are endless, a completely new system for producing forward force could be studied and implemented to fit the needs of a more power conscious community of the 21st century.

6.4 Overview of Cost Issues for Direct Hydrogen Fuel Cell Vehicle

Fuel cells are a key, enabling technology for many renewable energy systems and represent a critical a clean, distributed and diverse bridge to traditional fossil-fuel energy systems. Fuel cells and the associated hydrogen-based energy systems also provide a revolutionary opportunity to transform our energy system from one based on the instantaneous use of power generation to one where energy can be efficiently stored and dispatched.

Manufacturing costs of Direct Hydrogen Fuel Cell Vehicles (DHFCVs) are difficult to estimate due to early stage of commercialization and key uncertain variables, however, Using Deluchi's Lotus 1-2-3 EV cost and performance spreadsheet model, the manufacturing and lifecycle costs including FCV stack characterization can be calculated.

The costs for DHFCVs include the component costs and performance costs.

1. Fuel Cell Costs:

Both Department of Trade and Industry (DTI) and ADI Group, Inc. have estimated PEM fuel cell system costs in high volume, but different assumptions about efficiency and catalyst loading lead to very different results. The following equation is used in the calculation of the cost of the fuel cell costs:

$$C_{hv}=1{,}073+P_n*(18.70+(5.34+27*L_p)/P_d)$$

Where:

C_{hv} is high volume cost of PEM fuel cell system (in $)

P_n is net fuel cell peak power output, in Kw

L_p is total cell platinum catalyst loading in mg/cm2

P_d is cell peak power density, in w/cm2.

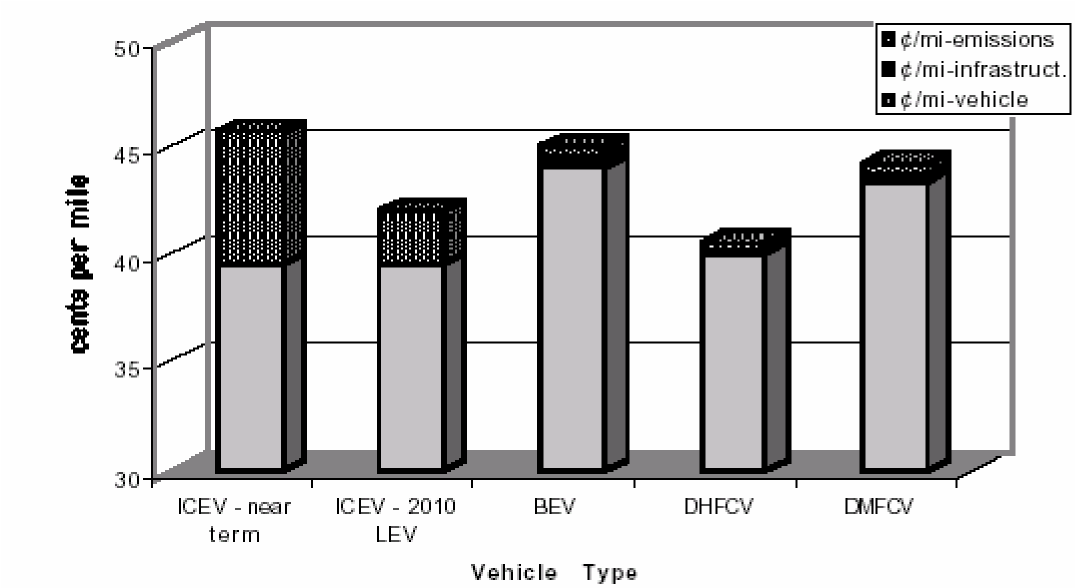
From the equation above, we can get that the cost for DTI—low efficiency, high power, low catalyst loading, is $60-70 per peak kW for 50-100 kW Fuel Cell (FC) systems for stack and auxiliaries; the cost for ADL—higher efficiency, lower power, higher catalyst loading is about $210 per peak kW for 50 kW FC system. Both system productions of about 500,000 units per year.

2. Performance Cost

While the introduction of fuel cell systems powered by renewably produced hydrogen will initially occur in small niches, renewable hydrogen production will grow as costs fall, particularly if aided by policies and regulations that specifically reward the use of hydrogen produced from renewals. An ideal policy would clearly articulate a transitional strategy to open markets, and reward clean energy generation. Once fuel cell system costs have declined – as do the costs of all new technologies -- the market and policy support can focus on hydrogen production from the cleanest and most sustainable sources, radically improving the efficiency and environmental performance of our national energy system.

In order for this to occur, however, policy changes are needed and R&D funding must be increased. Fuel cell technology has benefited from significant private and public investment, but too much emphasis has been placed on systems that produce hydrogen from fossil fuels and not enough has been placed on hydrogen-based systems using renewals. Significant development challenges remain for fuel cell systems, and government development assistance and program support from agencies and national labs can play a key role in overcoming these remaining hurdles.

***Figure 33*. Vehicle Lifecycle, Infrastructure, and Emission Costs: Year 2026 – High Prod. Volume Central Case (1997cent/mile)**



The above Figure 33 shows that the vehicle lifecycle, infrastructure, and emissions costs of future Fuel Cell Vehicles. The costs for the DHFCV are about 40 cents per mile, the cheapest performance price.

SECTION 7

7.1 SUMMARY

Whether fuel cells are feasible is still in question. According to the research and experiments conducted in the industry, it may be concluded that more research is needed to actually commercialize fuel cells. Fuel cells may be the next generation power source because no emission feature but the cost is still to high for mass production. There are many companies that are doing research on fuel cell technology for automobile application, but there is not a huge breakthrough on getting the price down. There are a number of small, portable fuel cells in development at various companies for low power needs. The availability of fuel cell products is an issue. There is not a company that has PEM fuel cells readily available for consumers. They are manufacturing these on a make to order basis.

Although PEMFCs are still very expensive mainly due to the manufacturing methods applied for both, raw materials as well as fuel cell stacks, presently placed orders range between 10,000 to 15,000 US$/$kW_{e,\ system}$. Nevertheless, the cost reduction potentials attributed to PEMFCs by specialists (technology specialists as well as manufacturing specialists) are huge and very promising. At present, most PEMFC companies (e.g. De Nora, H Power, Siemens, Daimler-Benz) agree that PEMFC system costs for fully integrated hydrogen fueled systems can be reduced. These costs would allow PEMFC systems to be applied economically in the field of dedicated electric power and low temperature heat production as well as in selected niche applications for fleet vehicles such as transit buses in national parks or spa resorts.

It is said in the industry that the cost goal is to get US$ 50/ $kW_{e,\ system}$ for PEMFC systems or US$ 70-100/ $kW_{e,\ system}$ including fuel reformer and gas purification technology, which are needed for large-scale market penetration into the automotive market. There is still a question about whether this can be achieved. On the other hand, several automotive companies have presently started investing huge amounts of capital to investigate the mass production and feasibility of necessary cost reductions. Daimler-Benz alone invests some $200 million DM during the years 1997 to 1999. Similar efforts are undertaken by the three U.S. automakers, by PSA and Renault in France and Honda and Toyota in Japan. Ford Motor Company recently showed their prototype hydrogen station to the industry and stated that they do not want to be behind the industry when fuel cells are mass used in an automobile application.

The strategies, for developing fuel cells, adopted by several companies differ quite substantially. There are companies which try to develop the markets via entering stationary dedicated power applications first, growing into bus and heavy duty applications and finally reaching the use in passenger cars. Among these companies, count De Nora, Italy, H Power, USA, and Siemens, Germany. On the other, there are industries, which plan to enter into passenger car applications directly, although some time later. Among these organizations count e.g. Chrysler, Daimler-Benz, Ford, GM, Renault and Toyota; all of them typically from the automotive industry sector.

Researchers indicate that some prerequisites need to be fulfilled for PEM fuel cell systems. If these are achieved, they can have a bright perspective in mobile applications. Some of these prerequisites can be listed as:

- Further reduction of weight and volume
- Reduction of operating pressures
- Reduction of noble metal contents
- Mass produced components (membranes, bipolar plates, heat exchangers, pumps, compressors, reformers, purification equipment)

- Industrial mass manufacturing processes
- Modular system configuration
- Mass production of electric drive motors

PEMFC systems already will have achieved competitive prices for decentralized stationary power applications before. Price reduction of PEMFC systems is expected in several years to come. In both cases, the infrastructural equipment (hydrogen storage equipment, refueling equipment, gasoline, diesel, methanol and natural gas reforming units, etc.) has to be made available at competitive prices and in a user-friendly manner.

If these market penetration rates can be achieved, PEMFC technologies will provide excellent opportunities to phase in renewable energies into the mobile fuel market and thus open the potential for significant CO_2 reductions. New business opportunities will be opened on several levels, i.e. for PEMFC component and system manufacturers, for suppliers of infrastructural equipment and for independent small-scale power producers.

This research and prototype application concludes that fuel cells, technically, can be used to power an automobile. The results of the experimentation can be listed as:

- Fuel cells can be used to power the toy car that uses 6 V and 1.64 amperage to operate.
- Fuel Cell generates continuous power, which might be used in automobile application.
- To maximize the power usage generated by the fuel cell, the electrical motor that uses the power needs to be compatible with it.
- The better rated the motor is, the higher performance one might get from a fuel cell.

- In automobile application of the fuel cell there is not an emission problem because there is not a combustion occurring.
- Fuel cells can be an alternative to batteries.
- Availability of fuel cell is still a problem.
- The question weather fuel cells are feasible in automobile application is still in question due to cost of production.
- Price reduction of infrastructural equipment such as hydrogen storage equipment, refueling equipment, gasoline, diesel, methanol and natural gas reforming units, etc. also have to be made available at competitive prices and in a user-friendly manner.
- While the introduction of fuel cell systems powered by renewably produced hydrogen will initially occur in small niches, renewable hydrogen production will grow as costs fall, particularly if aided by policies and regulations that specifically reward the use of hydrogen produced from renewals.
- An ideal policy would clearly articulate a transitional strategy to open markets, and reward clean energy generation.

References

1. Ford Shows Off New Hydrogen Refueling Station - Liquid and Gaseous - Unwraps H_2 I.C. Engine, Hydrogen & Fuel Cell Letter, hfcletter@mhv.net
2. Fuel Cells, Green Power, Sharon Thomas and Marcia Zalbowitz at Los Alamos National Laboratory.
3. Daniel M. Kammen, The Role of Fuel Cells in The Renewable Roadmap to Energy Independence, February, 2002
4. Timothy E. Lipman, Fuel Cell Vehicle Manufacturing and Lifecycle Cost Issues. January, 2002.
5. http://www.google.com/search?hl=en&lr=&ie=UTF-8&oe=UTF-8&q=Cost+for+DHFCV
6. Richard Count, Policies Affecting the Commercialization of Fuel Cell Vehicles, 1999.
7. www.energypartners.com
8. www.hpower.com
9. www.warsitz.com/education/kit.htm
10. http://www.doe.com
11. http://www.dri.edu/Projects/Energy/Fuelcells/Designs.html
12. http://www.ballard.com/trans_app.asp
13. Fuel Cell Handbook, 4th edition, by JH Hirschenhofer, DB. Staufer, R. R. Engleman, and M. G. Klett (1998)
14. http://www.spinglass.net/scooters
15. Dupont Co. Product Information Year 2000
16. http://www.copower.com
17. http://www.ott.doe.gov/documents/oaat_10.html
18. http://www.fuelcellstore.com/bcs_forcedflow_stacks.html
19. www.fuelcells2000.com
20. Energy Information Administration, Energy Facts-1999. EIA Report, U.S. Department of Energy, June 1999.
21. Atkin et al, Electric Vehicles; Prospect for Battery, Fuel Cell and Hybrid Power Vehicle, Financial Automotive, London, England, July 1998.
22. Cannon, J.S., Clean Hydrogen Transportation: Market Opportunity For Renewable Energy, Project Issue, No. 7, April 1997.
23. Corbett, M., Opportunities in Advanced Fuel Cell Technologies Vol. 1- Stationary Power Generation 1998-2008, Kline & Co. NJ, 1998.
24. Koppel, T., Powering the Future, John Wiley & Sons, 1999.
25. Lee, S.W., Laser PIV and PDPA Applications for Gas/Solid Flow Measurement in FBC, proceeding of ETCE 99, Feb. 1999.
26. Cohn, Arthur and Richard Goldstein. "High Efficiency Fuel Cell/Gas Turbine Combination Cycle."
27. PEM Fuel Cells in Stationary and Mobile Applications: infrastructural requirements, environmental benefits, efficiency advantages and economical implications by Reinhold Wurster, Dipl.-Ing., 01.10.97 Ludwig-Bölkow-Systemtechnik GmbH, Daimlerstrasse 15, D-85521 Ottobrunn Tel.: 49/89/608110-33, Fax.: 49/89/6099731, E-mail: wurster@lbst.tnet.de
28. Proton Exchange Membrane Fuel Cells as an Electrical Power Source: Recent Development at the University of Kansas by Trung Van Nguyen, Department of Chemical and Petroleum

Engineering, The University of Kansas Lawrence, Kansas 66045, 913-864-3938 (Phone), 913-864-4967(Fax), cptvn@kuhub.cc.ukans.edu
29. http://www.dais.net/home_page.html
30. http://www.electro_chem.com