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Over the years, ever since the boom of the industrial age, the advancement in vehicles and automobiles has been tremendous. From the slow and noisy open-air automobiles to the space-aged electric hybrid cars, the advancement of technology has inspired us to have better and faster engines. Unfortunately, during those past few years, the environment has also been ignored and various problems have come to our attention. About twenty-five to seventy-five percent of the chemicals that pollute the air are emitted by transportation vehicles. This causes smog, health problems, and most especially, global warming. The surface temperature of the earth is warming and has risen by 0.6 °C over the past 100 years. There is a natural greenhouse effect that contributes to warming. Greenhouse gases produced mostly by automobiles trap heat and radiation. Because of this, it warms the earth's atmosphere because they prevent a significant amount of radiation and heat from escaping into space. Concentration of greenhouse gases, especially CO_2, has increased substantially since the beginning of the industrial revolution. With global warming emerging, it has led to several chain events such as sea-level rising, depletion of the ozone, and having too much radiation in the atmosphere.

Aside from problems relating to pollution, the limiting supply of natural resources has also come to attention – particularly the oil supply. Today, half of the oil the USA uses is imported. Over the past 15 years, the oil consumption and imports has almost doubled in the USA alone. This level of dependence on imports (fifty percent) is the highest in US history defeating the 1970's "oil shock," and still continues to rise.

Though, we may call it an "advancement in technology," it also leads to a crisis of new problems relating to oil supply, pollution, and green house effects. Because of this, many automotive manufacturers are racing to produce a vehicle that does not upset the environment and does not depend on oil as well. Several hybrid vehicles have been tested such as methanol-run cars to battery-operated cars that showed outstanding success having no or low negative emissions yet posts a lot of challenges performance-wise and production-wise. The most current “future” car, which is starting to come to the automobile market today, is the hydrogen fuel cell. BMW, General Motors, Nissan, Daimler-Chrysler, Honda, Hyundai, and Toyota are already on the race to develop the most efficient hydrogen-powered prototypes. Due to its zero negative environmental impact, simple machination design, availability, safe chemical properties, and encouragement to use recyclable energy, and efficiency, hydrogen fuel cell proves to be one of the best choices of alternative fuel compared to the internal combustion engine.

The idea of using a fuel cell is not a new concept. The first fuel cell was built over a century ago during 1839 by Sir William Grove, a Welsh judge and scientist. However, interests in the fuel cell did not emerge until the 1960’s when the USA space program chose fuel cells over riskier nuclear power and more expensive solar energy. Fuel cells have been used in Gemini and Apollo aircrafts and still provide electricity and water for various space shuttles. Now, however, it is currently entering the automobile world to produce a quieter, simpler, and cleaner car (Fuel Cells 2000, par 1).

A fuel cell consists of two electrodes – the cathode (positive) and the anode (negative) – sandwiched around an electrolyte, which is made of a special polymer membrane. The hydrogen fuel is fed into the anode of the fuel cell. With the help of a catalyst, the hydrogen atom splits into a proton and an electron, which take different paths to the cathode. The polymer electrolyte membrane allows the proton to pass through. The electrons, on the other hand, are channeled through a circuit, which creates a current of electricity that can be utilized before they return to the cathode. Oxygen from the atmosphere enters the fuel cell through the cathode. Upon returning to the cathode, the electrons and protons of hydrogen and oxygen combine to form molecules of water, which is one of the byproducts (What is a Fuel Cell, par 2). Like batteries, fuel cells have a limited capacity to create a current of electricity. However, fuel cells are not thrown out or recharged when its available electrons are used up. Like a gasoline car, the fuel (hydrogen) is replenished (Fuel Cell Sandwich, par 2). By producing electricity on board, let's say – a vehicle, fuel cells eliminate the need for storage batteries, which add tremendous weight and space (O'Dell, par 12).

There are nine different types of fuel cells for different purposes. They are: phosphoric acid, molten carbonate (MCFC), solid oxide (SOFC), alkaline, direct methanol fuel cells (DMFC), regenerative fuel cells, zinc-air fuel cells (ZAFC), protonic ceramic fuel cells (PCFC), and the proton exchange membrane (PEM) fuel cell. They all differ in applications, operating temperatures, cost, and efficiency. The type of fuel cell used to power automobiles is known as the Proton Exchange Membrane (Solid Polymer) or the PEM fuel cell. This type of cell operates in relatively low temperatures of about 80 °C, has a high power density, can change their power output quickly (from high to low), and is suited for automobile applications where a quick startup is needed. According to the Department of Energy, "they are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries." The Fuel Cell 2000 homepage illustrates that the proton exchange membrane is made of a "thin plastic sheet, which allows only the hydrogen ions (positively charged) to pass through it. The membrane is coated on both sides with highly dispersed metal alloy particles (mostly platinum) that are active catalysts. The electrolyte used is a solid organic polymer – polyperflourosulfonic acid" (Types of Fuel Cell, par 2). Cell outputs generally range from 50 to 250 kW. The reaction of a single fuel cell produces a very low voltage; therefore, many cells must be combined, called a "fuel cell stack," to produce the electrical power needed to run a car (Running on Vapor, par 37).

The unique thing is that though it may operate through electricity like a batter-operated car, fuel cells require fuel just like an internal combustion engine. However, it is not of gasoline, diesel, or natural gas, but of the element hydrogen, which is the most abundant element in the universe. The Britannica Encyclopedia mentions that hydrogen is a colorless, odorless, nonpolluting, nontoxic yet flammable gaseous substance that is the simplest member of the family of chemical elements bearing only a proton of one positive electrical charge and an electron of one negative electrical charge. It takes up of

75% of the mass of all matter and 11% of the mass of water. Hydrogen has the highest coefficient of diffusion of all the gases, which means that it is lighter than air and escapes the atmosphere very quickly. Though hydrogen has the highest heat conductivity of all gases, which makes it flammable when in contact with air, but it is unlikely to explode compared to gasoline vapors (Ring, par 18).

There are many ways hydrogen can be provided to the fuel cell. One way is to refuel the fuel cell with hydrogen in gas form or in liquid form (both are elemental form). Gaseous and liquid hydrogen both must be highly compressed and isolated to be able to be stored in the vehicle. Another way is to get hydrogen from hydrocarbon fuels such as methanol, ethanol, gasoline, or diesel fuel. With this, a “fuel reformer” is needed to extract the hydrogen. The fuel is introduced to the vaporizer tank and converted into gases under high heat. The gases are oxidized or combined with air to produce hydrogen and carbon monoxide. Steam and air are introduced, along with a catalyst that converts the deadly carbon monoxide to carbon dioxide and hydrogen. By using a “reformer” to obtain hydrogen, the vehicle would not be zero-emission but eliminates the production of Nox, Sox, particulates, and other smog-producing agents. (Fuel Cell Vehicles, par 1). The most recent yet underdeveloped way is through renewable sources of energy like biomass, wind, hydroelectric, or solar power, which is at its infancy and planning stage.

The most significant and obvious advantage hydrogen fuel cell vehicles have is that the fuel cell itself has no negative environmental impact. The government of California considers the hydrogen fuel cell vehicle as a ZEV or a zero emissions. This means that any vehicle powered by hydrogen as a fuel cell elemental or reformed in any fossil fuel has very low or negligible emissions. The only by-products from hydrogen fuel (not reformed) cell are de-mineralized water, heat, and electricity; therefore this may dramatically reduce the problems of urban pollution. When hydrogen is burned in the fuel cell (in a flameless process), the resulting emission has no unburned hydrocarbons, no smoke, no carbon monoxide or carbon dioxide. If natural gas, gasoline, or fossil fuel is “reformed” (extraction of hydrogen) into hydrogen, emissions of carbon dioxide, nitrous oxides, sulfur oxides, harmful particulates, and other pollutants may be present but reduced to about 60% compared to just regular use of these fuels. With this fact, it is obvious that hydrogen fuel cell cars produce fewer "system-wide" releases of greenhouse gases.

Another advantage is its high fuel efficiency. Fuel cells "extract more power out of the same quantity of fuel when compared to traditional combustion power of gasoline" making it 30% - 90% more efficient than regular gasoline (Benefits of Fuel Cells, par 5). Peter Hoffman, an editor and publisher of The Hydrogen and Fuel Cell Letter and author of several hydrogen fuel cell related books argues that the hydrogen fuel cell engines can become more than twice as efficient as internal-combustion engines. Two-thirds of the oil we consume powers transportation vehicles, and half goes to passenger cars and light trucks. According to the US Department of Energy, there will be a cut of oil imports by "800,000 barrels a day," that is about 13% of the total imports if only 10% of the USA will switch to hydrogen fuel cell (Benefits of Fuel Cells, par 5). As of this moment, hydrogen fuel cells open the doors to the usage of renewable energy like biomass, solar energy, wind and hydro electricity which is advantageous to us when it comes to having a limited supply of fuel and oil.

Hydrogen fuel cell automobiles are more likely considered "advancement to battery-powered cars" (Fuel Cells 2000, par 9). They may have the advantages of a battery-powered car, yet they differ from them because they have the ability to refuel quickly and go longer between refueling. According to Argonne National Laboratory, the methanol fuel cell vehicles (with a reformer), or MFCVs, will achieve efficiency of 1.76 times greater than that of a gasoline internal combustion engine. The US Energy Information Administration's (EIA) 2000 outlook projects reported that the new fuel economy of gasoline could grow up to 31.4 mpg by the year 2010. With this information, by 2010, the MFCV's fuel economy will be much greater – 55 mpg gasoline gallon equivalent. By using pure hydrogen without the use of a reformer will even increase the amount of efficiency more.

Hydrogen fuel cells also have a lot of engineering benefits. Fuel cells are capable of operating on hydrogen alone or on any hydrogen reformed from any of the common fossil fuels we all use today (natural gas, gasoline, etc.) Therefore, with the use of a reformer, hydrogen can be extracted easily to almost anything, even water. Hydrogen can also be extracted from enzymes (bacteria and algae). Cyanobacteria, abundant single-celled organisms, produce hydrogen through its normal metabolic function. These bacteria can grow in air and water, and contain enzymes that absorb sunlight and energy and split the molecules of water, thus producing hydrogen. The only waste emitted with this produce is also water, which can be utilized, in the next metabolism. (Frequently Asked Questions, par 27).

Fuel cells also operate at low operating temperatures and pressures. A hydrogen fuel cell will only operate from 80° C to 1000° C, while an internal combustion engine will operate in temperatures as high as 2300° C. Due to the high temperatures of the internal combustion engine, engineers find it best to make a completely new engine model instead of alternating the hydrogen fuel to fit in internal combustion engines. Because hydrogen fuel stations operate quietly with zero or minimal emissions and do not require any drilling, it can be located and stationed anywhere – inside or outside. Gasoline stations, however, require location and drilling requirements which limits the flexibility of choosing an area.

Hydrogen fuel cells are also simple in design. They do not contain any moving parts compared to the internal combustion engine. General Motors unveiled the Autonomy last January 7, 2002, consisting of no pedals and no dashboard. Though investing for the research of the best hydrogen fuel cell vehicle is a hard and risky role, this company took the stand and premiered its first prototype at the Detroit Motor show. The show, consisting of more than 700 vehicles and out of all, General Motors' prototype which looked like a giant skateboard – stood out. It included a "low-slung chassis platform with four wheels attached to it" which gave the skateboard look. Software provides the car with a drive-by-wire control system, which is controlled by the driver from a single control stalk rising from the floor of the car. This eliminates the need for mechanical systems of wires and valves traditionally used to steer, power, and brake, which allows the driver to now sit wherever he or she wants (even the back seat.) It also eliminates the need of an engine compartment in the front since all the vehicle's power train is found in the wheel area. Without these mechanical parts, there is no need to buy motor oil, brake fluids, or transmission fluids. (GM Unveils Fuel Cell Car, par 7). Because of this, it allows hydrogen fuel cell cars to have a simpler design, higher reliability, and quiet operation, which is most likely not going to fail.

Safety within the passenger compartment is also another aspect that one must scrutinize. When one thinks about hydrogen, the words "Hindenburg" or hydrogen bomb" will pop in one's head. Many myths about hydrogen as the "explosive gas" have recently been dispelled. The most significant one was about the Hindenburg incident. But Addison Bain, a retired NASA safety expert who conducted a comprehensive investigation of this incident, explains that hydrogen was not the main cause of the fire. Studies show that the gas bags were made of cellulose acetate or cellulose nitrate and painted with aluminum flakes for insulation. Both were also ingredients for rocket fuel. Basically, Bain explained that the airship was painted with rocket fuel (Frequently Asked Questions, par 29). A hydrogen fuel cell car would carry about 0.8 [GJ] of hydrogen energy for a four-passenger car or 0.2 [GJ] per passenger. The hydrogen tanks are designed to survive 50-mph head-on collisions. These tanks are subjected to gunfire that will not make the tank explode; instead, the hydrogen will only leak through the bullet hole. This is very unlikely when it comes to gasoline tanks. In the case of gas leakage, since hydrogen is lighter than air and has a high diffusion rate, the escaped hydrogen will float up into the atmosphere quickly. Though hydrogen gas may ignite when it comes in contact with air, it does not explode, unlike gasoline vapors.

The major obstacle of using hydrogen as a fuel is that there is no portable way to store hydrogen in larger sizes (equivalent of an automobile tank of gasoline or an airplane tank to get fuel). Hydrogen requires a "new fuel distribution infrastructure." To carry hydrogen on a vehicle, it must be compressed to about 3000 lbs. per square inch. This is a lot of pressure to keep it contained in a stable state. Another solution may be converting hydrogen from gas to liquid. However, with this process, it requires not only very high pressure, it also needs to be chilled up to 423.2° C below zero. The container must be insulated to keep the hydrogen from warming up. Warming the liquid or lowering the pressure will only take place when the gas is being utilized by the fuel cell. Hopefully in due time, there will be a new solution to containing hydrogen. In the meantime, the best solution is to use methanol or any natural gas with a reformer to extract the hydrogen which is ready to be utilized by the fuel cell immediately.

Because hydrogen has so many modifications and has a costly distribution infrastructure, it can become costly, often as much as 50% more than regular diesel price at this moment. It is extremely costly when talking about dollars. A conventional car engine costs about $3000 to manufacture while a hydrogen fuel cell can cost $5000 for just the reformer alone. Building pure hydrogen-refueling stations would also cost about $470,000 each or $70,000 to modify a medium-size gas station into one that could deliver fuels needed by vehicles with reformers, according to the California Fuel Cell Partnership (Running on Vapor, par 14). The cost of the internal combustion engine is $50 per kilowatt of capacity. The hydrogen fuel cell, however, costs about $1500 – $3000 per kilowatt. Hydrogen fuel cells will have to be much cheaper in order for it to be placed into one of the commercial vehicles. One key reason is that not enough are being made to allow economies of scale. When Ford introduced its first hydrogen fuel cell car, it was too expensive. With the increase of mass production, hopefully the hydrogen-fuel cell cars will be much cheaper.

If one weighs the pros and cons of hydrogen-fuel cells, one would most likely conclude that the use of hydrogen-fuel cells has a lot of promise for a cleaner and brighter future. Despite the lack of technology to solve the problems brought about by the hydrogen-fuel cells (which in due time, may be able to be solved), hydrogen-fuel cell vehicles have much to offer, not only to the environment, but also the economy and the society. Already, Bush administration has helped finance the research of the FREEDOM Cars Program to develop fuel-cell-powered vehicles to promote a cleaner and brighter future last January 9, 2002. According to the Department of Energy (DOE) budget for the

Fiscal year 2003, $39.9 M will be for the hydrogen research program, which seeks to develop ways to make hydrogen a competitive fuel. Compared to last year's budget, the government increased the budget to an addition $10 M. The increased emphasis in the hydrogen research program reflects on more research and development on the engineering storage technologies, technology validation for wind/reversible fuel cells, the initiation of the Hydrogen Energy Development Initiative and increased outreach to certify technicians. Also, an additional $8.1 M on Fuel Cell Research and Development related programs, resulting in a $50 M total for the program. Based on the budgets, the Hydrogen Fuel and Fuel Cell research makes up most of the DOE budget for FY 2003, which emphasizes the attention the Bush Administration has given to find a better alternative fuel.

By increasing conservation and energy efficiency and aggressively using these clean energy technologies such as hydrogen-fuel cell cars, we can reduce our greenhouse gas emissions by significant amounts in the coming years and at the same time answer the limited supply of oil and decrease our dependence on imports of these fuels. Hydrogen fuel cell vehicles may be the solution to our problems and will hopefully unleash the possibility of a cleaner future. The race is on for a better and cleaner future.

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