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Hydrogen Fuel Cell

Saini, Richa

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Introduction

By the middle of the 21st century, the global community will be dependent on alternative fuels as energy sources. Alternative fuels, those that are not derived from oil, will have taken the place of fossil fuels in powering everything from automobiles, office buildings, and power plants to everyday household items such as vacuum cleaners and flashlights. Driven by environmental, health, economic and political concerns, the global community has been forced to begin developing technology and infrastructure to support the revolution fossil fuels to alternative fuels such as hydrogen. In particular, the world's leaders have targeted the automotive fleet and the internal combustion engine. By replacing the internal combustion engine in automobiles with the hydrogen fuel cell, we could achieve zero emissions of pollutants into the environment. The transformation of the existing transportation system is key to solving many of the world's environmental problems and significantly improving the quality of the air that we breathe. Here we will focus on the role that the Polymer Electrolyte Membrane (PEM) Fuel Cell, widely considered the most practical fuel cell, will play in the switch to alternative fuels (Wendyestela, 2001).

For correspondence:

Department of Physics, Gurukula Kangri University, Haridwar, Uttarakhand
Email: **kushwaha.richa@yahoo.in**

History of fuel cells

Sir William Grove (1811-96), a British lawyer and amateur scientist developed the first fuel cell in 1839. Grove's invention was based on idea of reverse electrolysis. The principle was discovered by accident during an electrolysis experiment. When Sir William disconnected the battery from the electrolyzer and connected the two electrodes together, he observed a current flowing in the opposite direction, consuming the gases of hydrogen and oxygen. He called this device a 'gas battery' (Bria cook, 2001)

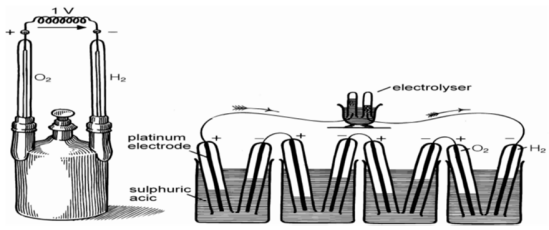


Fig. 3: Grove's 'gas battery' (1839) produced a voltage of about 1 volt, shown left. Grove's 'gas chain' powering an electrolyze.

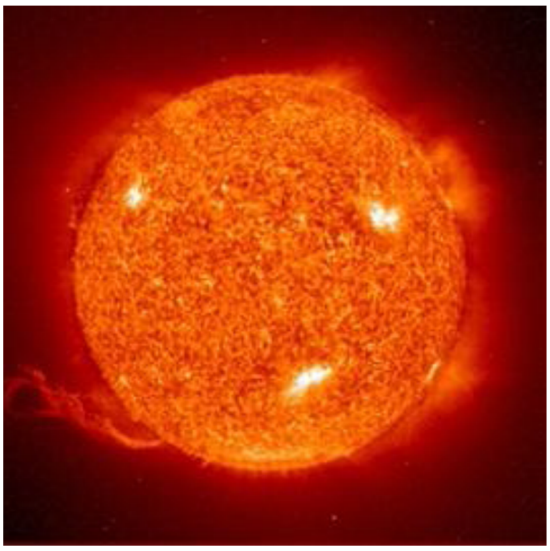
Significant work on fuel cells began again in the 1930s, In the 1950s Bacon successfully produced the first practical fuel cell, which was an alkaline version. It used an alkaline electrolyte (molten KOH) instead of dilute sulphuric acid.

In the early 1960s, General Electric (GE) also made a significant breakthrough in fuel cell technology. Through the work of Thomas Grubb and Leonard Niedrach, they invented and developed the first polymer electrolyte membrane (PEM) fuel cell. It was initially developed under a program with the US Navy's Bureau of Ships and U.S. Army Signal Corps to supply portable power for personnel in the field. Attracted by the possibility of using GE´s PEM fuel cell on the Apollo missions, NASA tested its potential to provide auxiliary power onboard its Gemini spacecraft. The Gemini space program consisted of 12 flights in preparation for the Apollo missions to the moon.

In the late 1980s and early 1990s Los Alamos National Laboratory and Texas A&M University also made significant developments to the PEM fuel cell. They also found ways to significantly reduce the amount of platinum required and developed a method to limit catalyst poisoning due to the presence of trace impurities in the hydrogen fuel (Los Alamos National Laboratory).

What Is Hydrogen?

Hydrogen is the simplest element known to exist. An atom of hydrogen has one proton and one electron. It is the lightest element and a gas at normal temperature and pressure. Hydrogen is also the most abundant gas in the universe, and the source of all the energy we receive from the sun. The sun is basically a giant ball of hydrogen and helium gases. In a process called **fusion**, hydrogen nuclei combine to form one helium atom, releasing energy as radiation. This radiant energy is our most abundant energy source. It gives us light and heat and makes plants grow. It causes the wind to blow and the rain to fall. It is stored as chemical energy in fossil fuels. Most of the energy we use originally came from the sun.



Source: NASA (Public Domain)

Hydrogen as a gas (H_2), however, doesn't exist naturally on Earth. It is found only in compound form. Combined with oxygen, it is water (H_2O). Combined with carbon, it forms organic compounds such as methane (CH_4), coal, and petroleum. It is found in all growing things—biomass.

Most of the energy we use today comes from fossil fuels. Only about nine percent comes from renewable energy sources. Usually renewable sources are cleaner, and can be replenished in a short period of time. Hydrogen can come from either renewable or

nonrenewable resources. Hydrogen is one of the most promising energy carriers. It is a high efficiency, low polluting fuel that can be used for transportation, heating, and power generation in places where it is difficult to use electricity. Hydrogen gas is so much lighter than air that it rises fast and is quickly ejected from the atmosphere. This is why hydrogen as a gas (H_2) is not found by itself on Earth.

Hydrogen has the highest energy content of any common fuel by weight (about three times more than gasoline), but the lowest energy content by volume (about four times less than gasoline). Hydrogen is not a primary energy source like coal and gas. It is an energy carrier. Initially, it will be produced using existing energy systems based on different conventional primary energy carriers and sources (Hydrogen, 2015).

Hydrogen fuel cell

A fuel cell is like a battery in that it generates electricity from an electrochemical reaction. Both batteries and fuel cells convert chemical energy into electrical energy and also, as a by-product of this process, into heat. However, a battery holds a closed store of energy within it and once this is depleted the battery must be discarded, or recharged by using an external supply of electricity to drive the electrochemical reaction in the reverse direction.

A fuel cell, on the other hand, uses an external supply of chemical energy and can run indefinitely, as long as it is supplied with a source of hydrogen and a source of oxygen (usually air). The source of hydrogen is generally referred to as the fuel and this gives the fuel cell its name, although there is no combustion involved. Oxidation of the hydrogen instead takes place electrochemically in a very efficient way. During oxidation, hydrogen atoms react with oxygen atoms to form water; in the process electrons are released and flow through an external circuit as an electric current. Fuel cells can vary from tiny devices producing only a few watts of electricity, right up to large power plants producing megawatts. All fuel cells are based around a central design using two electrodes separated by a solid or liquid electrolyte that carries electrically charged particles between them. A catalyst is often used to speed up the reactions at the electrodes (Fuel cell basics, fuel cell today, 2012).

Chemistry behind the technology

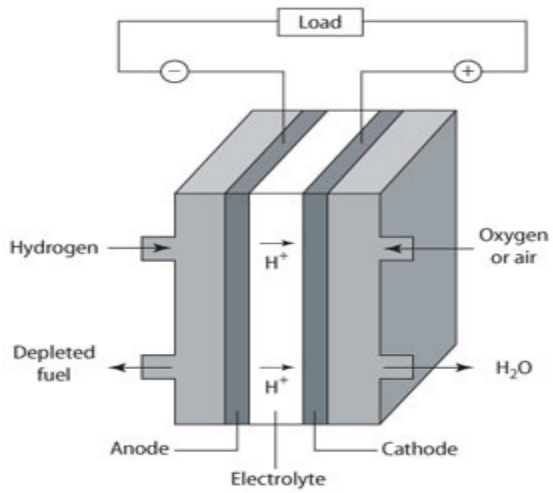
Oxidation

At the anode of the cell, a catalyst (platinum powder) is used to separate the proton from the electron in the hydrogen fuel.

Anode half-reaction:

$2H_2 \rightarrow 4H^+ + 4e^-$

$E^o = 0.00V$



Reduction

At the cathode of the cell, a second catalyst (nickel) is used to recombine the protons, electrons, and oxygen atoms to form water.

Cathode half- reaction:

$4H^+ + O_2 + 4e^- \rightarrow 2H_2O$

$E^o = 0.68V$

In electrochemistry, the E^o_{cell} value (energy) of a fuel cell is equal to the E^o of the cathode half-reaction minus the E^o of the anode half-reaction. For a hydrogen fuel cell, the two half reactions are shown above. So to calculate the energy of one fuel cell, we need to subtract the anode energy from the cathode energy. For a HFC, the E^o_{cell} = 0.68V – 0.00V which equals 0.68V
(http://www.fueleconomy.gov/feg/fuelcell)

Why hydrogen and hydrogen fuel cells

A sustainable high quality of life is the basic driver for providing a clean, safe, reliable and secure energy supply in world. To ensure a competitive economic environment, energy systems must meet the following societal needs at affordable prices:

– Mitigate the effects of climate change;

– Reduce toxic pollutants; and

– Plan for diminishing reserves of oil.

Failure to meet these needs will have significant negative impacts on:

– the economy;

– the environment; and

– public health.

(Community research, European commission, 2003).

The world has already begun the transition to cleaner fossil fuels containing less carbon and more hydrogen. As the world's supply of fossil fuels decreases, the shift to renewable energy sources will continue with a move to resources such as hydrogen, which human beings previously were unable to harness. There are five key policy reasons why this shift is necessary:

(1) The environment. Emissions from vehicles are the largest source of air pollution.

(2) Human health. More than 50,000 people per year may die prematurely from exposure to fine particulates emitted by trucks and buses, power plants and factories.

(3) Economics. The costs of producing oil continue to increase, as deeper wells are drilled farther and farther from markets in harsh climates.

(4) Energy Security. Military and political costs of maintaining energy security internationally are becoming untenable.

(5) Supply. World oil supplies are finite, and are expected to reach their peak as early as 2025 (Wendyestela, 2001).

Measures should therefore be introduced which promote:

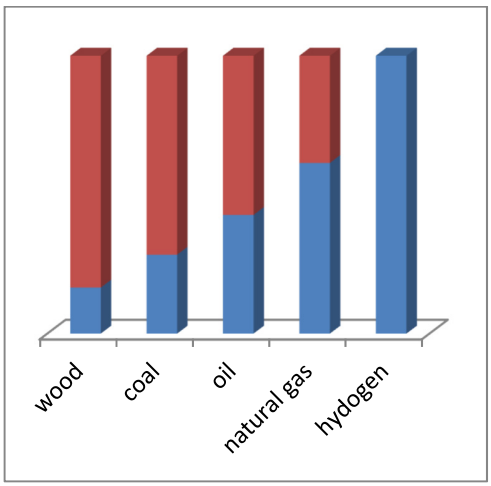
– more efficient use of energy; and

– energy supply from a growing proportion of carbon free sources.

The potential effects of climate change are very serious and most important of all, irreversible. World cannot afford to wait before taking remedial action, and it must aim for the ideal – an emissions-free future based on

sustainable energy. Electricity and hydrogen together represent one of the most promising ways to achieve this, complemented by fuel cells which provide very efficient energy conversion. Producing hydrogen in the large quantities necessary for the transport and stationary power markets could become a barrier to progress beyond the initial demonstration phase. If cost and security of supply are dominant considerations, then coal gasification with CO_2 sequestration may be of interest for large parts of world. If the political is to move to renewable energies, then biomass, solar, wind and ocean energy will be more or less viable according to regional geographic and climatic conditions. Regenerative hydrogen, and hydrogen produced from nuclear sources and fossil-based energy conversion systems with capture, and safe storage (sequestration) of CO_2 emissions, are almost completely carbon-free energy pathways.

As the hydrogen content in a fuel increases, the formation of water becomes more significant, resulting in proportionally lower emissions of carbon dioxide.

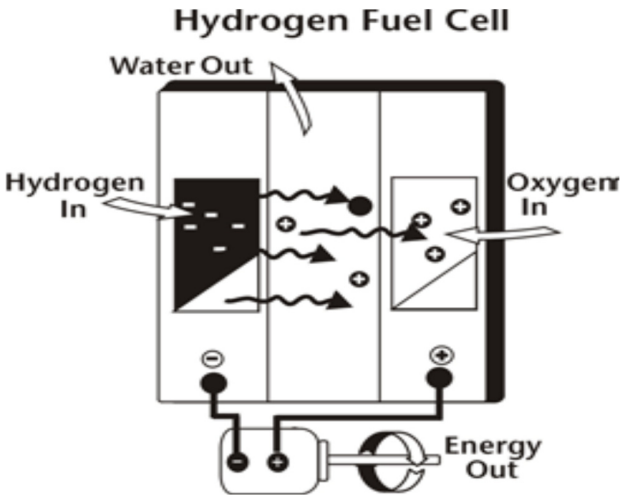


A World Issues…!!

- After fossil fuels, what will become the fuel of the future?
- Where Will Hydrogen Come From..??

Where Will Hydrogen Come From..??

- Hydrogen is not readily available for consumer use yet.
- To get around this problem, hydrogen will be extracted from other, more conventional types of fuels by a device called a reformer.
- A fuel like natural gas is reformed into hydrogen which will then go on to power a fuel cell.



Source: The National Energy Education Project (Public Domain)

- Natural gas comes from mostly the US, so even before the switch to pure hydrogen is made, we will get our fuel domestically.

Hydrogen atoms can be separated from water, biomass, or natural gas molecules. The two most common methods for producing hydrogen are **steam reforming** and **electrolysis** (water splitting). Scientists have

discovered that even some algae and bacteria give off hydrogen.

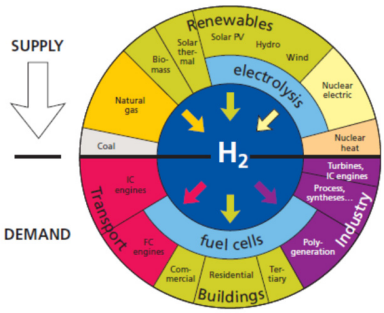
Steam Reforming Is a Widely-Used Method of Hydrogen Production

Steam reforming is currently the least expensive method of producing hydrogen and accounts for about 95% of the hydrogen produced in the United States. This method is used in industries to separate hydrogen atoms from carbon atoms in methane (CH_4).

Electrolysis, but Is Costly

Electrolysis is a process that splits hydrogen from water. It results in no emissions, but it is currently an expensive process. New technologies are currently being developed.

Hydrogen can be produced at large central facilities or at small plants for local use (Wendyestela, 2001).



- **Why Do We Need a New Fuel Source?**

  The solution is simple, but the implementation may take some time……
- Currently our machinery runs on oil
- Oil pollutes and there are limited supplies
- Hydrogen is the most abundant element in the known universe
- Hydrogen fuel cells do not pollute.

Parts of fuel cells

There are 4 main parts

1. **The Anode**
- The anode is the negative post of the fuel cell.
- It conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit.
- It has channels etched into it that disperse the hydrogen gas equally over the surface of the catalyst.

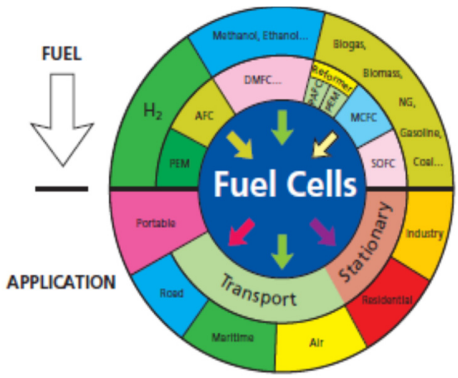
2. **The Cathode**
- The cathode is the positive post of the fuel cell.
- It has channels etched into it that distribute the oxygen to the surface of the catalyst.
- It also conducts the electrons back from the external circuit to the catalyst, where they can recombine with the hydrogen ions and oxygen to form water.

3. **The Catalyst**
- The catalyst is a special material that facilitates the reaction of oxygen and hydrogen.
- It is usually made of platinum powder very thinly coated onto carbon paper or cloth.
- The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen.
- The platinum-coated side of the catalyst faces the PEM.

4. **The Proton Exchange Membrane**
- The electrolyte is the proton exchange membrane.
- This is a specially treated material that only conducts positively charged ions.
- The membrane blocks electrons.

Types of fuel cell

Fuel cell types are generally classified according to the nature of the electrolyte they use. Each type requires particular materials and fuels and is suitable for different applications.



Types

PEMFC - Proton Exchange Membrane Fuel Cells

DMFC - Direct Methanol Fuel Cells

PAFC - Phosphoric Acid Fuel Cells

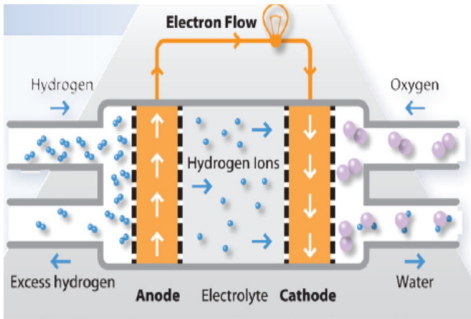
AFC - Alkaline Fuel Cells

SOFC - Solid Oxide Fuel Cells

MCFC - Molten Carbonate Fuel Cells

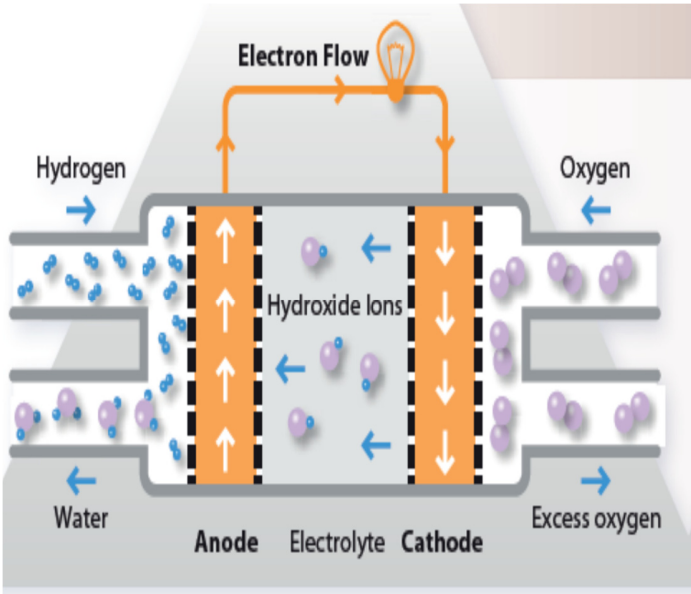
PEMFC – Proton Exchange Membrane Fuel Cells

- Electrolyte: water-based, acidic polymer membrane
- Use a platinum-based catalyst on both electrodes
- Generally hydrogen fuelled
- Also called polymer electrolyte membrane fuel cells
- Operate at relatively low temperatures (below 100°C)
- High-temperature variants use a mineral acid-based electrolyte and can operate up to 200°C.
- Electrical output can be varied, ideal for vehicles



Alkaline Fuel Cells – AFC

- Electrolyte: alkaline solution such as potassium hydroxide in water
- Commonly use a nickel catalyst
- Generally fuelled with pure hydrogen and oxygen as they are very sensitive to poisoning.
- Typical operating temperatures are around 70 ^{0}C
- Can offer high electrical efficiencies
- Tend to have relatively large footprints
- Used on NASA shuttles throughout the space programme.



Working of hydrogen fuel cell

A fuel cell is an electrochemical energy conversion device that converts hydrogen and oxygen into electricity and heat. It is similar to a battery in that it may be recharged while it is being used to generate power. Instead of recharging by using electricity, a fuel cell uses hydrogen and oxygen. Fuels cells differ from batteries in that a battery stores energy in chemicals contained in it, while a fuel cell acts as converter; reactants and products are in transit within the fuel cell.

There are four basic elements of a PEM fuel cell : The anode is the negative post of the fuel cell, which conducts the electrons that are freed from the hydrogen molecules. The cathode is the positive post of the fuel cell, which distributes the oxygen to the surface of the catalyst. The electrolyte, or "proton exchange membrane (PEM)," is considered to be the "heart" of the fuel cell, where the chemical reaction occurs. Two layers, a diffusion and reaction layer, surround it. Finally, the catalyst is a special material that facilitates the chemical reaction of oxygen and hydrogen. It is usually made of platinum powder thinly coated onto carbon paper or cloth. On the anode side of the fuel cell, hydrogen diffuses through the porous anode and diffusion layer up to the platinum catalyst. The reason for the diffusion current is the tendency of the hydrogen oxygen reaction. The catalyst and the temperature of 80 degrees Celsius cause the protons and electric to split.

$$H_2 \rightarrow 2H^+ + 2e^-$$

The hydrogen ion passes through the electrolyte while the electrons pass through an outer circuit. On the cathode side of the fuel cell, oxygen (O_2) is being forced through the catalyst, where it forms two oxygen atoms. Each of the atoms has a negative charge. The negative charge attracts the two H+ ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule.

$$2H^+ + \tfrac{1}{2}O_2 + 2e^- \rightarrow H_2O$$

The water resulting from this reaction is extracted from the system by the excess airflow.

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O$$

In the process described above, electrons generated at one side of the fuel cell and consumed at the other circulate in an external circuit which can drive, for example, an electric motor. The reaction in a single fuel cell produces only about 0.7 volts. To increase the voltage, fuel cells can be compiled together and the voltages are simply added up, creating a fuel-cell stack.

Advantages of fuel cells:

1. **It is readily available**

   Hydrogen is basic earth element and its very abundant. It produces a powerful clean energy source.

2. **It don't produce harmful emission**

   When hydrogen is burned, it doesn't emit harmful substances. Basically, it reacts to oxygen without burning and the energy it

release can be used to generate electricity used to drive an electric motor. Also, it doesn't generate carbon dioxide when burnt, not unlike other power sources.

3. **It is environmentally friendly**

   Hydrogen is non-toxic substances which is rare for a fuel sources. Other such as nuclear energy, coal and gasoline are either toxic or found in places that have hazardous environments. Because hydrogen is friendly towards the environments it can be used in ways that other fuels can't ever possibly match.

4. **It can be used as fuel in rockets.**

   Hydrogen is both powerful and efficient. It is energy to provide power for powerful machines such as spaceships.

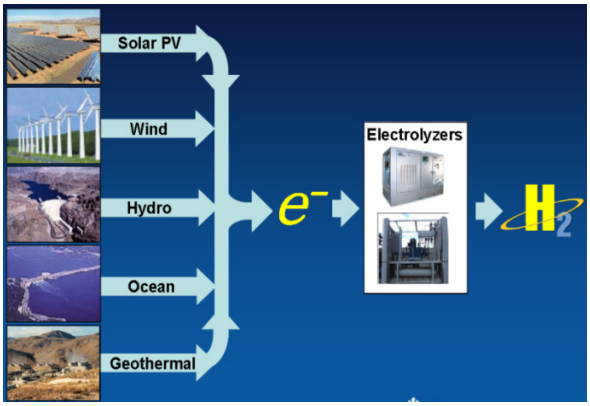
5. **It is efficient**

   Compared to diesel or gas, Hydrogen is much more fuel efficient as it can produce more energy per pound of fuel. Hydrogen is three times as powerful as gasoline and other fossil fuels.

6. **It is renewable**

   Hydrogen can be produced again and again. This means that with hydrogen , we get a fuel sources that is limited, basically hydrogen energy can be produced on demand.

   The best benefits occur when hydrogen is generated using renewable electricity and the electrolysis process is used.



7. **Reduces global warming**

Many members of the scientific community agree that "greenhouse gas" emissions are the cause of the warming of the earth's climate. The natural greenhouse gases include carbon dioxide (CO_2), water vapor (H_2O), nitrous oxide (N_2O), methane (CH_2) and ozone (O_3). it is clear that the general consensus is that something must be done to prevent further global warming. The United Nations has spoken on the issue and has emphasized that decisions made in the coming years will affect generations to come. It is clear that the energy efficiency, reducing the use of fossil fuels, transitioning to the use of renewable fuels and continued research are important and responsible steps. The transition to hydrogen fuel cell powered vehicles is a good beginning.

Disadvantages

1. **It is expensive**

   While widely available, hydrogen is expensive. It takes a whole lot of time to separate hydrogen gas from its companion substances, during all this process is come expensive.

2. **It is difficult to store**

   Hydrogen is very hard to move around when speaking about oil , that element can be sent through pipelines. When talking about hydrogen , just moving even small amounts is very difficult. For that reason only, the transport and storage of such a substance is deemed impractical.

3. **It is not easy to replace exiting infrastructure**

   Gasoline is still being widely used to this day. And as of the moment, there just isn't any infrastructure that can support hydrogen as fuel.

Uses or applications of hydrogen fuel cells:

- **Hydrogen Vehicles**

  Combustion chamber and cooling system modifications are done in order to prevent detonation before spark or within the intake which had been a problem in the past.

  Specifically designed, dedicated engines will use superchargers or turbochargers to supply boost.

  The components of a fuel cell electric vehicle of FCEV are different because they do not contain engines…instead the engine has been replaced with a fuel cell stack (multiple fuel cells together) to act as the source of power generation. power can directly power motors to propel the vehicle or be used in conjunction with batteries to improve efficiency.

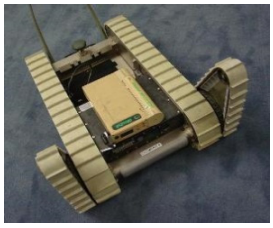
Performance

When a vehicle has been properly modified or purpose built the hydrogen powered vehicle may return better performance than conventional vehicles. Odorants are not added to hydrogen as is done with compressed natural gas and liquefied petroleum gas, for this reason hydrogen monitors should be installed at facilities.

There are many different uses of fuel cells being utilized right now. Some of these uses are…

- Power sources for vehicles such as cars, trucks, buses and even boats and submarines

- Power sources for spacecraft, remote weather stations and military technology




- Batteries for electronics such as laptops and smart phones


- Sources for uninterruptable power supplies.

- **Hydrogen in the Home and Office**

- Hydrogen fuel cells will power and heat homes and offices.

- Hopefully this will start in about 20 years.
- The hydrogen will come from natural gas that has gone through a reformer.
- Hydrogen cars can be refueled in the garage by a hydrogen powered house.
- **Hydrogen in Politics**
- Much of the world's and America's oil comes from the Middle East.
- Hydrogen fuel cells mean a decreased need for Middle Eastern oil
- Hydrogen fuel cells can be used to power third world
- In underdeveloped countries, the governments would not have to go broke importing oil
- Solar or wind power collectors could produce energy which would make hydrogen.
- Possible economic collapse in main oil exporting nations and in places like Saudi Arabia, this could lead to revolution.

The Future of Hydrogen

The use of hydrogen raises concerns about safety. Hydrogen is a volatile gas with high energy content. Early skeptics had similar concerns about natural gas and gasoline—even about electricity. People were afraid to let their children too near the first light bulbs. As hydrogen technologies develop, safety issues will be addressed. Hydrogen can be produced, stored, and used as safely as other fuels. As a domestically produced fuel, hydrogen has the potential to reduce our dependence on foreign oil and provide clean, renewable energy for the future.

- Today, the prospect of fuel cells is being chased very rapidly.
- Automakers worldwide are all attempting to be able to mass produce a vehicle that is powered by hydrogen.
- Some industry leaders are even attempting to create a hydrogen hybrid vehicle.
- Only time will tell where it all goes…

Conclusion

As our demand for electrical power grows, it becomes increasingly urgent to find new ways of meeting it both responsibly and safely. In the next hundred years, the world as we know it will undergo dramatic changes. As the world's supply of fossil fuels begins to reach total depletion, the leaders of government, industry and science scramble to find answers to the inevitable energy crisis.

Hydrogen fuel cells will dramatically change our cars, how are homes and businesses are powered and heated, and it both positively and negatively change places like the Middle East and third world countries. They will also clean up the world's air.

Focusing on and developing renewable energy resources will not only dramatically affect the air quality and the environment, but it will also level the playing field in the global political arena. Implementing clean energy technology over the next century could save money, create jobs, reduce greenhouse emissions and sharply reduce air and water pollution. Clearly renewable energy is the key to sustainable development.

References

Bria cook (2001): An introduction to fuel cells and hydrogen technology)

Community research, European commission (2003)

Fuel cell basics, fuel cell today (2012)

http://www.fueleconomy.gov/feg/fuelcell.

Hydrogen (2015): Secondary energy infobook, the need project.

Wendyestela (2001): Hydrogen fuel cell technology and its environment benefits.