# Advanced Regenerative Fuel Cells: Characteristics and Application

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**Abstract.** Nowadays, with the extreme increase of carbon emissions and the consumption of non-renewable resources, the earth's environment has a huge impact. More countries are adopting new carbon policies, and more companies are building new electric cars. Electric vehicles have a great advantage in harmful gas emissions and energy saving compared with ordinary fuel cars. The few disadvantages of electric vehicles are limited to the efficiency of battery supply and the lack of widespread implementation resulting in poor mobility. However, most electric cars today are powered by hydrogen fuel cells. This article will mainly discuss the working principle, the main characteristics and practical applications of the hydrogen fuel cells in professional fields. We mainly collected some information and data and visited many websites and papers on the hydrogen fuel cell for some study and summary.

**Keywords:** hydrogen fuel cell, working principle, advantages and disadvantages, environment, applications.

## 1. Introduction

An effective way to limit carbon emissions is using fuel cells, which can provide electricity taken by the reaction of hydrogen and oxygen from electrolytic water. There are different fuel cells such as solid oxide fuel cell (SOFC), hydrogen fuel cell, direct methanol fuel cell (DMFC). All these different fuel cells can be used in separated areas. Hydrogen is a clean fuel that, when consumed in a fuel cell, produces only water [1]. SOFC is a high-temperature fuel cell with a high operating temperature. It can also form a combined cycle with a gas turbine, suitable for distributed power generation. Direct methanol fuel cell is also a type of proton exchange membrane fuel cell, similar to hydrogen fuel cell except that the fuel is methane instead of hydrogen. Daimler Chrysler and Ballard have successfully developed the world's first methanol fuel cell equipped car, "Gorcat." The fuel cell has an output power of 6kW, a power generation efficiency of up to 40%, and a working temperature of 110 °C. However, hydrogen fuel cells tend to be the most widely used fuel cell nowadays.

## 2. The Working Processes of Hydrogen Fuel Cell

Most current hydrogen fuel cell electric vehicles are powered by a proton exchange membrane technology, not by burning hydrogen [2].

## 3. The Influences on the Surrounding Environment

There tend to be great advantages for electric vehicles, such as saving resources and reducing different kinds of pollutions. As early as the end of the 19th century, the beginning of the 20th century, there were comparisons between steam cars, internal combustion cars and electric cars. Electric cars are far more energy-efficient than the other two, while noise and air pollution are lower. Nowadays, electric vehicles have developed very fast and have been introduced much new technology which can

increase the exchange efficiency and reduce the resources used. Hydrogen fuel cells have two major impacts on today's earth, saving non-renewable resources and reducing environmental pollution and emissions. The first major impact is the conservation of non-renewable resources. Compared with cars, hydrogen fuel cells do not use oil, one of the rarest energy sources on earth.

In contrast to fuel-cell electric vehicles, which run on other energy sources, there is plenty of hydrogen on earth, saving many other resources. Another major impact would be a significant pollution reduction. First, hydrogen fuel cell vehicles can reduce the noise generated by many internal combustion engines. Then electric cars can also reduce the emission of many harmful gases. Ordinary cars will produce a lot of carbon dioxide and nitrogen dioxide in driving. These harmful gases will not only cause air pollution but also form acid rain and the greenhouse effect. Compared to other fuel cells, the only product of hydrogen fuel cells is water, which has no impact on the environment.

## 4. The Policies Related to Hydrogen Fuel Cells

In recent years, global carbon emissions have been on the rise, and the direct cause of this situation is global economic development and scientific and technological progress. Therefore, more and more countries focus on reducing their own carbon emissions, and automobile emissions are important factors affecting carbon emissions. More and more car companies are making electric cars, and more and more countries are making laws and policies on electric cars. The European Commission has set tough carbon emissions standards for cars and lorries to cut emissions by 100% by 2035. This means that gasoline-powered internal combustion engine cars will be eliminated by 2035. According to Fig.1, it shows the price of selected energy carriers in MJ from 1999 to 2004. Although price fluctuation was existed, the prices for these five energy forms still increased in five years' time.

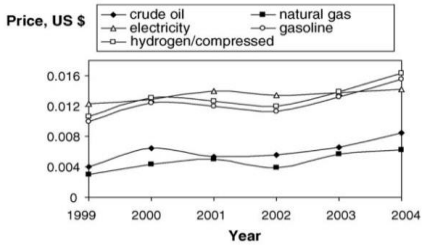



**Fig.1.** Prices of selected energy carriers in MJ from 1999 to 2004 [3]

## 5. The Advantages of Hydrogen Fuel Cells

### 5.1. No Pollution

Fuel cells are environmentally friendly. The most typical conventional backup power solution does so through electrochemical reactions instead of burning (gas, diesel) or storing (batteries). Due to people's neglect of environmental problems in the past hundred years, global environmental deterioration has become an undeserved price of modernization. In recent years, air pollution, acid rain, greenhouse effect and ozone layer destruction have become global serious environmental problems, threatening the survival of human beings and attracting the attention of all mankind [3].

### 5.2. No Noise

Electric vehicle noise mainly comes from the vehicle power system and non-power system noise [4]. The fuel cells operate quietly, making about 55dB of noise, about the level of a normal conversation.

### 5.3. Distinctions Between Hydrogen Fuel Cells and Dry Batteries

A dry battery is a kind of energy storage device that stores the electric energy when needed to release; Hydrogen fuel cells are strictly electricity-generating devices that convert chemical energy directly into electricity, like power plants [5].

## 6. The Disadvantages of Hydrogen Fuel Cells

Hydrogen fuel cells cost 100 times more than gasoline engines, a price the market cannot afford. With a maximum output power of 60 kilowatts, the hydrogen fuel cell vehicles consume only 1.2 kilograms per 100 kilometers, about the same as 4 liters of 93 gasoline. Hydrogen refueling stations will also be built. Toyota has significantly reduced the cost of fuel cells to $69,000, providing 100 KW of power and a range of 700 km. It will launch in North America and Japan in the first half of 2015.

## 7. Fields of Application and Current Installations

Hydrogen fuel cells are used in a wide range of fields. As a promising new power source, hydrogen fuel cells are used in large power stations, portable power sources, emergency power sources, home power sources, and transportation such as aircraft, cars, warships and so on. The advantages include clean energy conversion, high conversion efficiency. Here are some of the applications in the world.

### 7.1. Hydrogen Fuel Cell Vehicles

They work as follows: delivered the hydrogen fuel cell anode plate (cathode), through the role of catalyst (platinum), the electron in a hydrogen atom is separated, lose electron hydrogen ions (protons) through the proton exchange membrane, to fuel cell cathode plate (anode), an electron is not through the proton exchange membrane, the electron, only through an external circuit, reached the fuel cell cathode plate, thus generating a current in the external circuit. When the protons reach the cathode plate, they recombine with oxygen atoms and hydrogen ions to form water. Through the inverter, controller and other devices, the electricity from the fuel cell supplies power to the motor, and then through the transmission system, drive axle. Other wheel rotation can make the vehicle on the road. Compared with traditional cars, fuel cell vehicles have an energy conversion efficiency of 60-80 percent, two to three times that of internal combustion engines. Fuel cells run on hydrogen and oxygen. The product is clean water and works without carbon monoxide, carbon dioxide, and sulfur and particulate emissions. Therefore, hydrogen fuel cell vehicles are the real sense of zero emissions and zero car pollution. Hydrogen fuel is the perfect automotive energy.

### 7.2. Aircraft

The fuel cell is a kind of electricity generating device, but unlike the general non-rechargeable battery, which is discarded after use, and unlike the rechargeable battery, which must be recharged after use, fuel cell. A fuel cell works with two electrodes, one filled with an electrolyte and a permeable film between them. Hydrogen enters the fuel cell from the anode, and oxygen (or air) enters the fuel cell from the cathode.

Due to the fuel cell is using a chemical reaction, not only completely free from contamination but also avoid the problem of traditional battery charging time-consuming, is currently the most promising new energy ways. Boeing said it was a first in world aviation history and heralded a greener future for the aviation industry. Small planes take off and climb using a mixture of electricity from conventional batteries and hydrogen fuel cells. The plane flew for about 20 minutes at 1,000 meters and about 100 kilometers per hour. The technology is important for Boeing and "green for the future" of the aviation industry. The small aircraft, converted from an Austrian diamond two-seat propeller-powered glider, is equipped with proton exchange membrane fuel cells and lithium-ion batteries. With a wingspan of 16.3 meters and a fuselage of 6.5 meters long, the small plane weighs about 800

kilograms and can accommodate two people. The pilot was the only person on board during the test flight. Inside the cabin, conventional batteries sit in the single passenger seat, and behind the pilot is an oxygen tank similar to the one used by divers. Boeing says the plane can fly for up to 45 minutes without producing "any noise".

Hydrogen fuel cells generate electricity by converting hydrogen to water and produce no greenhouse gases. Besides heat, water vapor is the only byproduct of hydrogen fuel cells. The technology could provide auxiliary power for large aircraft, but that would require a technological breakthrough. Boeing's hydrogen fuel-cell aircraft is a technological breakthrough. Still, the head of research and technology at Boeing Europe, Michael Escati, says hydrogen fuel cells can power small planes but are not the main power for large airliners. The technology could provide auxiliary power for larger aircraft, but Neves Lapena, a Boeing engineer working on the test flights, would require a technological breakthrough. Boeing says it will continue to develop the potential of hydrogen fuel cells to improve the environment. The International Energy Agency says widespread use of hydrogen and hydrogen fuel cells could reduce oil, natural gas and coal, which produce greenhouse gases.

### 7.3. Other Areas

According to the Energy Storage International Summit, the adoption of hydrogen fuel cells is accelerating in developed countries. Japan will build 100 hydrogen refueling stations by 2015, 13 of which have already been completed. One of the examples which applies electrolysis technology to power generators is from a well-known Japanese electrical and electronic company TOSHIBA. The brand name is called H2Rex. It is a box-shaped generator that only emits water. Once hydrogen refueling stations are widely available,

The configuration of the H2Rex is divided into two parts, a water tank and a generator set. Cold water enters the water cooler of the generator set from inside the tank. The generator extracts oxygen from the air and then infuses hydrogen. The two are ionized in the battery pack to generate direct current, converted into alternating current and exported through the inverter. The heat generated during this period will continue to be collected through the waste Heat Recovery unit at the bottom of the tank. The water-cooling device will also contribute to heat release.

There are some key features of the H2Rex. The first feature is the high energy efficiency, including low exhaustion and high availability of electricity. After two battery packs, the hydrogen gas was consumed by 80 percent and finally reached the Hydrogen Circulating Pump for reuse. The hydrogen utilization rate reached 96 percent when the Hydrogen Circulation pump was not turned on. In terms of the total energy efficiency, we have to compare the hydrogen fuel cell to the conventional steam power generator. It is powered by burning oil and coal. The boiler heats the water and runs the turbine, which powers the generator. The thermal efficiency of steam power plants is approximately 42 percent. However, the H2Rex produces 50 to 55 percent of electricity and the remaining 40 to 45 percent of heat is partly recovered and used. So, it is far more efficient than the conventional generators [6].

The European Union recently approved an increase in fuel cell bus projects. Hyundai Motor's IX35 fuel cell model was rolled out in March 2012 and planned to start mass production in 2015 [7]. The public-private partnership will focus on building hydrogen energy infrastructure, which will be called H2USA. Hyundai Motor has held a mass production ceremony for its hydrogen fuel cell electric vehicle at its Ulsan plant. It will start producing Tucson IX hydrogen fuel cell electric vehicles from the end of this month [8].

During the 2008 Olympic Games, 20 hydrogen fuel cell cars independently developed by China were put into operation, the first batch of fuel cell cars to obtain the national road license, The Tongji University participated in the development [9]. On June 30, 2010, Shandong Dongyue Group announced China's independent research and development of chlorine and alkali per-fluorinated ion membrane, fuel cell membrane to achieve domestic production. After 8 years of scientific research, the monopoly of the United States and Japan on this technology has been broken, solving the major bottleneck of hydrogen fuel cell production, making China the third country in the world with this

technology and industrialization capacity. The high-energy hydrogen fuel cell, developed by Japanese electronics manufacturer ROM, along with Aqua Fairy and Kyoto University, uses a chemical reaction between calcium hydride and water to generate five watt-hours of electricity from a single cell measuring less than three cubic centimeters [10]. It can be used in many electronic devices, including smartphones, or backup power in an emergency.

## 8. Efficiency

Considering the heat exhaust utilization, it can reach more than 80%, which is 2~3 times the thermal efficiency of an ordinary internal combustion engine. The wide and diversified sources of hydrogen fuel optimize the energy consumption structure. Hydrogen fuel used by fuel cells comes from a wide range of sources. Much hydrogen energy is stored in water and produced by water decomposition or renewable energy sources. Fuel cells do not depend on petroleum fuel, and various renewable energy can be converted into hydrogen energy to be used effectively, reducing the dependence on petroleum resources and optimizing the composition of transportation energy. A hydrogenation drive mileage is long. Hydrogenation time is short. It can run 600 to 700 kilometers once and can be filled up in 3 to 5 minutes with smooth operation and low noise.

## 9. Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) The advantages of hydrogen fuel cells are obvious, especially in reducing harmfulness to the environment. It owes to the clean chemical reaction and the clean products.

(2) The policies related to hydrogen fuel cells are mostly positive due to enhancing people's environmental awareness.

(3) Hydrogen fuel cells producing not only no pollution but also no noise. The power generation efficiency is above 50%, which means little energy loss. However, there are also limitations, such as the high cost and the undeveloped technology.

(4) It is applied in various fields, including aeronautics and astronautics, aircraft, automobiles, etc. As a new energy technology in the future, many of the large companies, including boing, TOSHIBA are developing new forms of products

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