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THE RESEARCH ON WHETHER HYDROGEN

FUEL CAN REPLACE ORDINARY FUEL IN THE FUTURE

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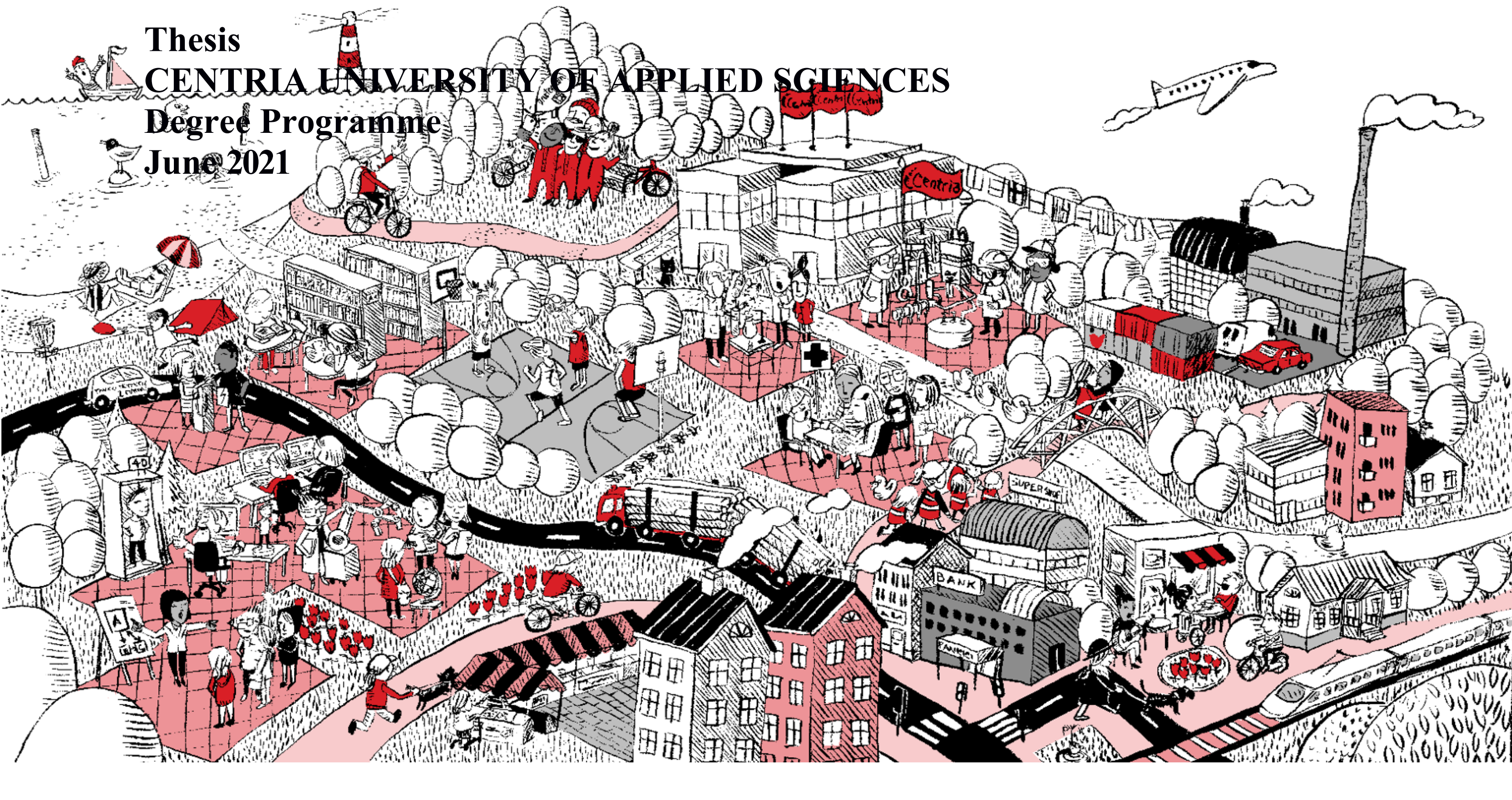

ABSTRACT

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Name of thesis THE RESEARCH ON WHETHER HYDROGEN FUEL CAN REPLACE ORDINARY FUEL IN THE FUTURE		
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The aim of this thesis is to review hydrogen energy and hydrogen fuel, and to describe the prospect of hydrogen as energy carrier. This thesis,firstly, introduces the use of hydrogen as energy carrier, hydrogen energy system and technology, including the production, utilization, storage and distribution of hydrogen. Secondly, the economics of hydrogen energy system and its social and political significance are discussed. Finally, the important role of hydrogen energy in the short and long term are discussed, and the future development of hydrogen energy system is prospected in detail.

Key words
Hydrogen, clean energy, hydrogen fuel,hydrogen cell

CONCEPT DEFINITIONS

HFC
Hydrogen fuel cell

FCV
Fuel Cell Vehicle

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CONCEPT DEFINITIONS
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1 INTRODUCTION

First of all,the reason choosing this topic is: In the past five years,the traditional fuel pollution to the Earth's atmosphere has been getting more and more serious. Currently, experts are working on hydrogen fuel cell vehicles. The hydrogen fuel cell replacethe traditional fuel. People know that hydrogen is the bestpollution-free fuel for human use. The product of hydrogen combustion is only water. Theoreticallyhuman beings can obtain an inexhaustible amount of energy through the periodic variation of hydrogen and water.Therefore, as an alternative to conventional fuel, hydrogen has been widely concerned.From developed countries to developing countries, increasing energy consumption is a universal driving force for improving the quality of life of all societies.

However, the current dependence on fossil fuel energy has produced harmful side effects: environmental pollution that threatens human health, carbon dioxide emissions that accelerate global warming, and geopolitical tensions caused by the uneven distribution of fossil resources around the world. The challenge people face is how to find efficient ways to produce, provide, and use energy to improve the quality of life without threatening the environment and climate, nor straining geopolitical relations.

The use of hydrogen has the potential to significantly reduce the impact of mobility on global warming and urban air pollution, and to overcome the current dependence on oil for transportation. Hydrogen is not a major source, but it is an energy carrier that can be produced from any major source, including fossil, renewable and nuclear energy. However, key factors related to production costs, the lack of a large-scale distribution network and the low capacity of existing on-board storage equipment limit their proliferation, particularly in the transport sector.

This thesis work focuses on the characteristics, advantages and disadvantages of hydrogen fuel cell. According to the characteristics and basic principle of hydrogen fuel cell, the performance of hydrogen fuel cell and dry cell was compared, the development status of hydrogen fuel cell in automobile and aerospace was introduced, and the application of hydrogen fuel cell was summarized.The thesis discusses different methods of hydrogen production and storage, as well as major infrastructure issues. The potential and obstacles of different hydrogen storage methods have been demonstrated in detail, which need to meet the strict requirements of vehicle mileage, whether the current liquid fuel can meet the requirements of hydrogen fuel, and whether it can replace the traditional fuel on a large scale in the future. Finally, the future development of hydrogen fuel is proposed and prospected.

2 HYDROGEN FUEL CELL

Hydrogen fuel cell (HFC) is a device that converts the chemical energy of hydrogen and oxygen into electricity. The basic principle is the reverse reaction of electrolyzing water. Hydrogen and oxygen are supplied to the anode and cathode respectively. After hydrogen diffuses outwards through the anode and the electrolyte reacts, electrons are released to the cathode through the external load. (Hashimoto 2019.)

2.1 The history of hydrogen and fuel cells

The basic inventions of hydrogen and fuel cell technology (hydrogen fuel engines and fuel cells) were popularized in the early 19th century and are today closer to social use than ever before.The first hydrogen-powered internal combustion engine was built by Isaac de Rivaz in 1806 (Galich & Marz 2012.)The invention did not receive much attention from society for the next fifty years, and it was not until 1863 that the next generation of vehicles, powered by hydrogen-powered combustion engines, was built by Etienne Renaud. However, the technology disappeared from aero space again until Rudolf Allen developed a hydrogen-powered two-stroke cycle in the late 1920s. In the following decades, this development was followed by a single concept study, but none of it progressed beyond the experimental stage.(Galich & Marz 2012.)

The history of fuel cells has similar properties. The mechanics of fuel cell technology were discovered in 1838 by the German-Swiss chemist Chamban and the English lawyer and natural scientist Sir William Grove, working independently of each other. In 1889, Ludwig Mond and Charles Langer conducted a thorough technical study of the fuel cell that gave it its true name. It doesn't until 1932 that the first basic electrolyte fuel cell model was built by Francis Thomas Bacon. This development followed the construction of the first fuel-cell-powered aircraft in 1959.Until the late 1960s, hydrogen fuel engines and fuel cells started with the basic inventions of one man, followed by single inventions and extensive time intervals, during which time these technologies did not receive much attention from society. By the late 1960s, however, initiatives aimed at promoting social acceptance of hydrogen and fuel cell technologies began to increase worldwide. (Galich & Marz 2012.)

2.2 The characteristics of hydrogen fuel cell

Fuel cell has no pollution to the environment. It uses an electrochemical reaction rather than combustion (gasoline diesel) or energy storage (battery) the most typical of the traditional backup power solution. Combustion releases pollutants like CO_x, NO_x, SO_x gases and dust. As mentioned above, fuel cells produce only water and heat. If hydrogen is produced from renewable energy (photovoltaic panelswind power) the whole cycle is a complete process that does not produce harmful emissions. (Gold 2015.)

The fuel cells are quiet and the noise is only about 55 DB which is about the level of normal conversation. This makes the fuel cell suitable for installation indoors or where there are limits on noise outside. (Gold 2015.)

Fuel cell power generation efficiency can reach more than 50%, which is decided by the conversion nature of fuel cell, the direct conversion of chemical energy to electrical energy, without the intermediate conversion of thermal energy and mechanical energy. (Gold 2015.)

2.3 Application of hydrogen fuel cell

Fuel cells which convert hydrogen and oxygen into electricity and waterare an attractive alternative to fossil-fuel combustion engines because of their efficiency, versatility and environmental protection. Fuel cell power generation has a potential efficiency of 60%. (Crabtree & Dresselhaus2008.) Electrical energy can be used directly or converted into motion, light or heat. Gasoline engines, by contrast, operate at 25 percent efficiency and are almost exclusively devoted to producing power. According to the U.S. Department of Energy's analysis of the fuel cell learning demonstration results of 77 fuel cell vehicles in the first two years, the fuel cell efficiency at 1/4 power reached 52.5 to 58.1%, close to the target efficiency. (Crabtree & Dresselhaus2008.)

Figure 1 shows the basic operation of a fuel cell. Hydrogen goes to the anode (red), where it is forced to dissolve into protons and electrons. Protons enter the polymer electrolyte membrane (green), where they migrate to the cathode (blue) for electron conduction. Electrons work electronically through an external circuit before reaching the cathode. The cathode reacts electrons, protons and oxygen molecules to produce water. The net inputs of the fuel cell are hydrogen and oxygen, and the net outputs are water, electricity and heat. (Crabtree & Dresselhaus2008.)

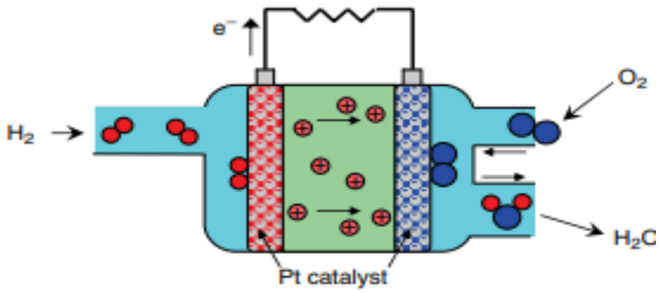

FIGURE 1 Hydrogen Fuel Alternative (Adapted from Dresselhaus 2008.)

2.3.1 Hydrogen fuel cell vehicle

Fuel Cell Vehicle (FCV) is considered as an important characteristic of vehicle based on fossil fuel, which may promote the sustainable development of automobile industry. With their zero-emission, efficient and diverse sources of hydrogen energy, they are ideal solutions to climate change and the global energy crisis. (Hao,Wang&Zhang 2020.) In recent decades, governments and major automotive groups have attached great importance to the research and development of fuel cell-related technologies. Considerable resources have been devoted to the research and development of fuel cells and hydrogen energy technologies. (Hao,Wang&Zhang 2020.)

The hydrogen fuel cell vehicle works by sending hydrogen gas to the anode plate of the fuel cell, where an electron in the hydrogen atom is separated by the catalyst platinum, and a hydrogen ion (Proton) that has lost an electron passes through the Proton Exchange Membrane, to the fuel cell Cathode Plate (Cathode) and the electron cannot pass through the Proton Exchange Membrane, this electron, can only pass through the external circuit, to the fuel cell cathode plate, thus generating an electric current in the external circuit. When the electrons reach the Cathode, they recombine with oxygen and hydrogen ions to form water. As the oxygen supplied to the cathode plate can be obtained from air so long as the anode plate is supplied with hydrogen, the Cathode Plate is supplied with air, and the water (steam) is taken away in time, the electricity can be provided continuously. The power from the fuel cell is supplied to the motor by the inverter, the controller and so on, and then the wheels are driven by the transmission system, the drive axle. (Binder, Faltenbacher& Fischer 2005.)

Hydrogen is an extremely light and flammable gas. Hydrogen is 114th the density of all gases, and at atmosphere and 0°C the density of hydrogen is about 0.0899g/l. (Fréchette 2015.)It evaporates easily in the air and leaks easily, making it difficult to control. Hydrogen has a wide range of applications and a very low ignition energy (about 10 times lower than traditional hydrocarbons).In addition, there is much need to consider the risks involved in the production, storage, transportation and use of hydrogen fuel. Especially in the design, development, manufacture, driving, parking, and accident of fuel cell vehicles, the safety of hydrogen should be greatly concerned. (Yamada, Fujikawa & Umeda 2007.)

To ensure the safety of hydrogen fuel cell vehicles in use, four main measures are adopted and emphasized in relevant standards: Strict requirements are imposed on the design, production and assembly of vehicle-mounted hydrogen loading systems (including hydrogen storage containers, hydrogen storage container valves, hydrogen transmission pipelines.) to prevent possible hydrogen leakage.The hydrogen concentration monitoring function, the hydrogen leakage alarm function and the hydrogen cut-off function should be included in the design of the vehicle leakage safety management system as a minimum. When designing the body structure, avoid using sealed or semi-sealed spaces that may lead to hydrogen accumulation. In the design and development of fuel cell engine, hydrogen circulating pump and effective control strategy should be used to reduce the hydrogen emission of fuel cell engine when it is idling or running. (Janssen 2007.)

Considering the current status of hydrogen safety in mixed space, each standard focuses on two aspects: hydrogen leakage requirements under static conditions and hydrogen emission requirements under operating conditions. When vehicles are parked in garages or other poorly ventilated spaces for a long time, hydrogen leakage requirements under static conditions are mainly related to hydrogen safety. As far as the hydrogen emission requirements for operating conditions are concerned, the focus is on the hydrogen safety of the vehicle during start-up, idling or shutdown of the vehicle in the garage or other mechanically ventilated spaces. (Janssen 2007.)

The risks associated with hydrogen in a mixed space are much higher than in an open space. Therefore, the safety design of the sealed chamber is very important. For passive protection, a complete explosion-proof design, including explosion-proof nozzles, fans, cables and other components, must be used to avoid risks such as electric sparks. In order to eliminate the electrostatic phenomenon quickly and effectively, the whole test chamber is also grounded. In terms of active protection, the hydrogen concentration sensor is required to monitor the hydrogen concentration level in the laboratory throughout the process. When the hydrogen concentration is too high, the test chamber will issue sound and visual alarms, and automatically activate the emergency ventilation function to quickly discharge hydrogen from the cabin to ensure safety. (Vondrák, Klápště, Velická 2003.)

Therefore, from the safety point of view, in the design and development of Hydrogen Safety Test Chamber for fuel cells, explosion protection, sealing, ventilation simulation, hydrogen concentration measurement and emergency measures (such as audible and visual alarms, automatic emergency ventilation) should be considered. (Vondrák, Klápště, Velická 2003.)

2.3.2 Aerospace field

Hydrogen fuel cells have been successfully used in space flight since the 1960s. The Apollo spacecraft, which shuttles between space and Earth, is equipped with such a small and large device (Saad, Hassine &Elfahem 2014.)At present, all kinds of aircraft are using dedicated aviation fuel. The aviation fuel is petroleum product, and the combustion tail gas contains the nitrogen oxide.At present, flight altitude for each kind of civil aviation aircraft and the partial military aircraft is in the atmosphere stratosphere.Therefore, the aircraft tail gas decomposes the ozone under the photochemical reaction, which has become one of the important pollution sources of the ozone hole in the atmosphere.

With the continuous progress of human civilization, the human demand for energy is ever increasing. The non-renewable energy sources such as coal and oil are being almost exhausted and the ecological damage and environmental pollution caused by the exploitation and utilization of such energy sources are also becoming increasingly serious. The development and utilization of new clean energy has become an important goal of mankind. Hydrogen is clean, safe, and an ideal fuel. Mankind has begun a long-term exploration and practice in the utilization of hydrogen energy. (Saad, Hassine &Elfahem 2014.)

With the development of human spaceflight, hydrogen energy has been widely used in this field. As the lowest molecular weight substance in nature, hydrogen has the incomparable characteristics in mass. Scientists are increasingly using liquid hydrogen and oxygen as spacecraft propulsion fuel. Since the 1990s, nanotechnology has been developed.Human beings are constantly making new discoveries and breakthroughs in the microscopic world at the atomic level. With nanotechnology, new synthetic materials can be synthesized to achieve desirable combination of material structures at the atomic level.

Hydrogen can be stored in the form of atoms in these new materials in the atomic pipeline and hydrogen energy storage guarantee. (Saad, Hassine &Elfahem 2014.)

In fact, hydrogen has attracted more attention due to its excellent properties and high energy content in aerospace and energy industry. For example, liquid hydrogen (LH_2) is becoming an alternative fuel for aircraft. As a result, aerospace manufacturers are expected to provide sufficient flight time capacity, ranging from a few minutes to a few days. Still, using a hydrogen system can be dangerous, because hydrogen is easy to leak because of its smallest molecules. Therefore, it is necessary to establish a safe and reliable hydrogen leakage prevention system. The development of safety protection systems is understandable for hydrogen leak detection, such as catalysis, thermal conductivity electrochemistry resistance, functional basis of work, mechanics, optics and acoustics. All of these systems vary in their measurement range, sensitivity, selectivity, and response time. Especially, the optical system using fiber grating technology has some particularity due to its low measurement accuracy. (Alipour & Sheykhan 2017.)

The use of hydrogen energy as power can reduce aircraft flight load, provide more load for civil aircraft and military aircraft to achieve a longer range of power guarantee. The hydrogen energy replaces the traditional energy to enter the high energy consumption aviation industry, which may reduce the traditional non-renewable energy consumption, thus avoiding the environmental destruction to a large extent. The application of hydrogen energy in aircraft can reduce the exhaust pollution of existing aircraft, improve the power system of aircraft, and even bring about a new revolution in the aviation industry. It is hopefully predicted that the next generation of aviation technology will be promoted by hydrogen energy technology which will benefit humans in the new century. (Stern 2019.)

2.3.3 Aircraft Application

Boeing conducted three hydrogen fuel cell test flights from February to March 2008 in the Spanish town of Ocania, and the successful test flights are of historic significance. Small aircraft take-off and climb using a combination of conventional batteries and hydrogen fuel cells. After climbing to a cruising altitude of 1,000 meters, the plane cut off the power of its conventional batteries, which are powered only by hydrogen fuel cells. The plane flew at an altitude of 1,000 meters for about 20 minutes at a speed of about 100 kilometers per hour. The technology means a lot to Boeing and gives "Green Hope" for the future of the aviation industry. (Janić 2011.)

The small plane is a modified version of the Austrian Diamond twin-prop powered glider with Proton Exchange Membrane fuel cell and lithium-ion battery. Inside the cabin, traditional batteries sit on the only passenger seat, and the pilot has a scuba tank behind him. Boeing says the plane will fly for up to 45 minutes without making any noise. Hydrogen fuel cells generate electricity by converting hydrogen into water without producing greenhouse gases. Aside from heat, water vapor is the only product produced by hydrogen fuel cells. Boeing's hydrogen fuel-cell aircraft brought a technological breakthrough, but Boeing's (European) research and Technology Division This technology may provide auxiliary power for large aircrafts, but it will require a technological breakthrough. (Janić 2011.)

The technology has some technical limitationssuch as the rapid growth in demand for cleaner,safer and more efficient vehicles in the face of rising fuel prices, environmental pollution and global warming. Boeing's hydrogen fuel-cell aircraft is a technological breakthrough, but ESCATI, head of research and technology at Boeing (Europe) says hydrogen fuel cells can provide flight power for small aircraft but not major power for large passenger jets. Boeing will continue to exploit the potential of hydrogen fuel cells to improve the environment. In addition, the International Energy Agency is also supporting the use of hydrogen and hydrogen fuel cells, which can reduce the consumption of oil, natural gas and coal, which can produce greenhouse gases. (Alipour&Sheykhan 2017.)

2.4 The difference between hydrogen fuel cell and traditional battery

A dry cell or battery is an energy storage device that stores electrical energy and releases it when needed while a hydrogen fuel cell is strictly a power generation device, like a power plant, an electrochemical power plant that converts chemical energy directly into electrical energy. In addition, the electrode of hydrogen fuel cell is made of special porous material which is a key technology of hydrogen fuel cell. It not only provides a large contact surface for gas and electrolyte but also plays a catalytic role in the chemical reaction of hydrogen fuel cell. (Rosen & Fayegh 2016.)

2.5 Development Status of hydrogen fuel cell

As a truly "zero emission" clean energy, the application of hydrogen fuel cells in developed countries is accelerating. Japan will build 100 hydrogen stations by 2015,13 of which have been completed.The European Union recently approved a programme to add fuel cell buses; Hyundai's IX35 mass produced fuel cell model was done in March 2012 and is scheduled to start production in mass production. This shows that fuel cells have really moved from the laboratory to the industrialization.Compared with lithium batteries, it has the advantage of zero pollution. South Korean automaker Hyundai Motor, German automaker Mercedes Benz, Japanese automakers Nissan Motor Co and Toyota Motor Corp. have reached agreements with the U.S. Department of Energy to begin manufacturing hydrogen-powered vehicles, the Energy Department said. This public-private partnership will focus on the construction of a hydrogen energy infrastructure, which will be called H2USA. (Alipour & Sheykhan 2017.)

At the European level, the Netherlands, Denmark, Sweden, France, Britain and Germany have reached an agreement to jointly develop and promote hydrogen vehicles, with each country building a European network of hydrogen facilities and co-ordinating energy transmission. The UK government has proposed to develop hydrogen fuel cell vehicles with a target of 1.6 million by 2030 and a 30-50 per cent market share by 2050. (Bulletin 2000.)

China's first hydrogen fuel cell electric locomotive has taken four years to develop and could be used in industrial applications, such as mine tractors. In addition, during the 2008 Olympic Games, China's self-developed 20 hydrogen fuel cell cars were put into operation, which were the first batch of fuel cell vehicles to obtain the national road permit. (Bulletin 2000.)

3 LIQUID HYDROGEN FUEL

Hydrogen fuel is liquid hydrogen fuel. Burning a gram of hydrogen releases 142 kilojoules of heatthree times as much as gasoline. Its burned product is water, no ash and waste gas,which will not pollute the environment.Hydrogen is a colorless gas.It burns the product is water, no ash and waste gas, will not pollute the environment. Hydrogen fuel is extremely light,and much lighter than gasoline, natural gas and kerosene, making it less convenient to carry and transport, but hydrogen, as a fue,l is still considered to be the most ideal energy source for the 21st century. Hydrogen fuel with the outstanding characteristics of energy is pollution-free, highly efficient, recyclable. (Janić 2011.)

3.1 Characteristics and advantages of liquid hydrogen fuel

Hydrogen burns clean, producing no environmentally harmful pollutants such as carbon monoxide, carbon dioxide, hydrocarbons, lead compounds and dust particles other than water and a small amount of hydrogen nitride, and this small amount of hydrogen nitride after proper treatment will not pollute the environment. Moreover , combustion of water can continue to produce hydrogen for repeated recycling. Produced water is non-corrosive and non-destructive to equipment. (Mutolo 2019.)

The calorific value of hydrogen other than nuclear fuel is the highest among all fossil fuels chemical, fuels and biofuels with a calorific value of 142.351 kj/kg, three times that of gasoline.(Mutolo 2019.) What is important is that it burns well, ignites quickly, has a wide flammable range when mixed with air, and has a high ignition point and burns fast. (Mutolo 2019.)

Hydrogen is widely distributed in nature. Water is like the great container of hydrogen, containing 11% of it. Soil contains about 1.5% hydrogen; oil, coal, natural gas, plants and animals contain hydrogen. The main body of hydrogen is in the form of compound water, and about 70% of the Earth's surface is covered by water, with a largestorage, so it can be said that hydrogen is "inexhaustible" energy. (Mutolo 2019.)

3.2 Disadvantages of hydrogen fuel

The main disadvantage of hydrogen fuel is its high cost. Liquid hydrogen, typically obtained from natural gas, costs almost three times as much as conventional jet fuel. There are no natural hydrogen molecules in nature, so they have to be extracted from other compounds. At present, there are two main hydrogen production methods, one is water electrolysis, which is a commonly used technology to produce high purity hydrogen the cost is very high. The second is the rupture of the liquefied petroleum gas. The cost of the technology is low, but the purity of hydrogen is low and the purification is difficult. The cost of hydrogen production is high regardless of the technology used. Although the cost of hydrogen is falling as technology advances, it is still much higher than fossil fuels. (Kurnia &Sasmito 2020.)

4 HYDROGEN STORAGE

From the point of view of clean energy production hydrogen seems to be the most appropriate solution to overcome the current energy and environmental crisis. It is widely available in the form of water and can be extracted from solar wind or other clean sources of energy. Therefore, hydrogen energy and hydrogen fuel cells are considered ideal. However, this does not take into account the risks involved in production storage transport and use. (Hallaj & Kiszynski 2011).The storage density of hydrogen storage is lower than that of gasoline storage in both mass and volume. On the basis of mass high energy storage density can be obtained by using fat liquid hydrogen storage technology, which is about 80% of gasoline hydrogen storage density. The highest hydrogen storage capacity can be obtained under no load conditions using the hydride storage method. Because of its low density and small molecules, it may leak from a sealed container. This is a particular problem with the use of hydrogen in automobiles. (Schlapbach 2002.)

Governments in many countries and international organizations such as the European Community have pushed for hydrogen fuel cells to be used in cars. Based on the results reported in the literature, the electrochemical behavior of the most promising fuel cells (polymer electrolyte membrane fuel cells) is discussed. In addition, considering the influence of non-electrochemical factors, it is found that its application prospects are not very bright. In addition, hydrogen-rich gases produced by small organisms contain carbon dioxide and small amounts of Co, and their use can easily lead to poisoning of the platinum gas by diffusion anodes in fuel cells. And the hydrogen storage problem has not been solved. (Schlapbach 2002.)

Hydrogen is the lowest density gas at room temperature, and its melting point is also the lowest. In order to store hydrogen, hydrogen gas must be compressed, while liquid hydrogen storage requires low temperature conditions or pressure-resistant containers. Hydrogen molecules are small in size, low in density, easy to leak, flammable and explosive, causing the its storage to be a problem. Even liquid hydrogen is much less dense than other liquid fuels.(Yaliwal & Banapurmath 2021.)

Liquid hydrogen must be stored in an ultra-low temperature environment of less than 200 degrees Celsius, otherwise it will be vaporized, and it takes a lot of money to store it for a long time. In addition, the high cost of producing liquid hydrogen, the weight of the container containing liquid hydrogen, large volume, complex internal structure, and easy explosion of liquid hydrogenhave caused big challenges to the aviation industry under the existing technical conditions. The biggest disadvantage of storage and transportation is that it is more difficult to find a gas that is more explosive than hydrogen in the world. (Yaliwal & Banapurmath 2021.)

Therefore, the safety requirements are high and it is difficult to find a gas that is lighter than hydrogen in the world. Even if it is transported by high pressure, the volume is large, soultra high pressure transportation is required, and the compressor requirements are also demanding. Therefore, the economic transport radius of hydrogen is small, and the hydrogen-producing regions are usually separated from the regions where hydrogen is used. Therefore, in spite of the actual very low cost of producing qualified hydrogen , it is difficult to produce hydrogen in the transportation and storage, which also faces the problem of high transportation and storage costs. (Huggins 2016.)

The use of hydrogen for transportation, personal electronics and other portable power applications requires an effective hydrogen storage medium. Existing technology for hydrogen storage is limited to compressed gas and liquefaction, both of which are used now in demonstration vehicles. Compressed gas, even at the highest practical pressure of 10,000 psi, is still a bulky way to store hydrogen that requires a significant fraction of the trunk space in a small car to enable a 500 km driving range. Liquid hydrogen takes up slightly more than half the volume of 10,000 psi compressed gas, but it loses 30–40% of its energy in liquefaction. (Sánchez &Motta & Dimitratos 2016.).Although gas and liquid storage are useful as temporary options in a provisional hydrogen economy, more compact and efficient storage media are needed for a mature hydrogen economy. (Sánchez & Motta & Dimitratos 2016.)

The most promising hydrogen storage routes are in solid materials that chemically bind or physically adsorb hydrogen at volume densities greater than that of liquid hydrogen. The challenge is to find a storage material that satisfies three competing requirements: high hydrogen density, reversibility of the release/charge cycle at moderate temperature in the range of 70–100°C to be compatible with the present generation of fuel cells, and fast release/charge kinetics with minimum energy barriers to hydrogen release and charge. (Trohalaki & Uno 2014.)

The first requires strong chemical bonds and close atomic packing; the second requires weak bonds that are breakable at moderate temperature; and the third requires loose atomic packing to facilitate fast diffusion of hydrogen between the bulk and the surface, as well as adequate thermal conductivity to prevent decomposition by the heat released upon hydriding. Although several materials have been found that satisfy one or more of the requirements, none has proven to satisfy all three. In addition to these basic technical criteria, viable storage media must satisfy cost, weight, lifetime, and safety requirements as well. (Sánchez & Motta & Dimitratos 2016.)

Two recent developments in materials science hold promise for meeting the difficult hydrogen storage challenge. The first is the rapid progress in nanoscience in the past five years. The small dimensions of nanoscale materials minimize the diffusion length and time for hydrogen atoms to travel from the interior to the surface. The large relative surface area provides a platform for dissociation of molecular hydrogen to atomic hydrogen, a prerequisite for diffusion and for chemical bonding with the host. The surface area can be tailored with a monolayer of catalyst to promote dissociation, and surface curvature can be adjusted through the size of the nanoparticles to create unbonded orbitals that promote reactivity with hydrogen. (Trohalaki & Uno 2014.)

The second promising development for hydrogen storage materials is the growing ability of density functional theory to numerically simulate material behavior. Density functional theory implemented on computer clusters is now in widespread use for the calculation of the electronic structures, crystal structures, bond strengths, and heats of reaction for many multielement compounds. The number of compounds that can be simulated and the level of comprehensive information about their structures and stability far exceed what can be determined experimentally by discovery synthesis in the laboratory on the same time scale. This potentially powerful tool for numerically screening materials is now being applied to hydrogen storage compounds. A recent study examined 300 candidate compounds for their structures, hydrogen storage capacities, and hydrogen decomposition temperatures. (Huggins 2016.)

It should be noted that due to the importance of the automotive industry, most attention has been focused on transportation applications. The transition from modern CO_2-emitting energy systems based on hydrogen and fuel cell technology to CO_2 free energy systems is closely linked to the development of sustainable transport systems. (Huggins 2016.)The goal of the programme is to use renewable energy to produce hydrogen, which can then be used as a transportation fuel to power fuel-cell-powered vehicles.

4.1 Challenges in production

The challenge in production is to find a source of hydrogen that meets the needs of a mature hydrogen economy, rather than relying on fossil fuels as feedstock. Hydrogen production from natural gas is a widely used process, and if enough gas is produced to power the world's cars and light trucks, it will reduce the global supply of methane and make natural gas as politically sensitive as oil. In addition to fossil fuels, possible sources of hydrogen include the reforming of biomass carbohydrates or the thermal decomposition, electrolysis or photochemistry of water molecules. While these non-fossil hydrogen production routes are attractive and may be feasible, they require breakthroughs in materials research to find effective and stable catalysts to reduce barriers to energy production. (Schüth 2009.)

In addition to transportation, hydrogen cells and fuel cells can make an important contribution to clean and efficient energy use as stationary power generation for grid distribution, battery alternatives for personal electronics, and stationary or portable emergency power supplies. For large-scale stationary applications, continuous operation of solid oxide fuel cells in the 800-1000°C range is a priority technology for economies of scale. (Dresselhaus 2008.)

Using hydrogen as a clean fuel presents many challenges. One problem is the design of fuel cells that use more energy from the reaction of H_2O with O_2 than from combustion. A typical hydrogen fuel cell must use a proton exchange membrane to separate the anode (high purity H_2) from the cathode (O_2) because the corresponding electrocatalyst (platinum or platinum with certain other metals) is not selective between H_2 and O_2. Highly selective catalysts make proton exchange membrane unnecessary and can even generate energy from very low levels of H_2 in the air. (Schüth 2009.)

While a mature hydrogen economy requires technical and economic solutions for production, storage and use, there is value in implementing any one of these solutions without adopting a holistic approach to the others. Hydrogen fuel cells can be used in large stationary devices for community heating and electricity, as well as in small personal electronic devices. But they do not solve the problem of in-car storage and transportation. Hydrogen storage, which can be used for intermittent renewable energy sources such as solar and wind, cannot be used to produce hydrogen on a large scale. As a highly storable energy carrier, hydrogen has significant versatility, enhanced by its compatibility with electricity, but safely stored energy carriers form the backbone of the energy distribution system. Thus, while a full hydrogen economy including production, storage and use should be the ultimate goal, a partial realization of hydrogen as a storable energy carrier for stationary and personal fuel cell applications is its own ideal outcome. (Schüth 2009.)

5 EVOLUTION OF A HYDROGEN ECONOMY

The development of a hydrogen economy requires that the challenges of production, storage and use be addressed simultaneously, which is much more difficult than any of the three issues alone. People are still far from a viable solution for fossil-free production and solid-state storage. Unlike the earlier energy shifts from wood to coal and from horses to disruptive innovations, none of these components has yet completely replaced fossil fuel energy to provide a significantly cheaper and better performing alternative. Disruptive innovations that can lead to a full hydrogen economy for production and storage can only come from high-risk, high-return research into basic materials, rather than a step-by-step approach. (Ju, Xie & Lin 2020.)

However, the value of the hydrogen economy goes well beyond transportation. Hydrogen as an energy carrier has great appeal in many applications. Once produced it is environmentally friendly, and hydrogen is as attractive as electricity, becoming the world's most versatile and fastest-growing energy carrier. Hydrogen can be converted efficiently and flexibly into other forms of chemical, thermal, or electrical energy. (Kurnia & Sasmito 2020.)

Hydrogen and electricity are closely related to nature because they can be interchanged with high efficiency through the electrochemistry of fuel cells and electrolytic cells. Hydrogen stores energy indefinitely in chemical form at high density, whereas electricity is usually produced simultaneously and lacks convenient high-density storage. (Dresselhaus 2008.) The intermittent nature of renewable power and the diurnal and seasonal fluctuations in demand make local hydrogen storage and conversion to electricity a strong and natural option.

The close connection between hydrogen and electricity provides an attractive way for the development of hydrogen economy. The hydrogen used to generate electricity can be obtained from the gasification of coal, which can capture carbon dioxide more easily and at a lower cost than existing pulverized coal burning plants. (Sahaym & Norton 2008.)

6 INNOVATION AND DEVELOPMENT OF HYDROGEN FUEL

In order to realize the promise of hydrogen fuel as an efficient, sustainable and environmentally friendly fuel, extensive innovation and development of methods for the production, storage and use of hydrogen fuel are required.(Dresselhaus 2008.) The energy chains and technical challenges for creating a viable hydrogen economy are shownin figure 2.

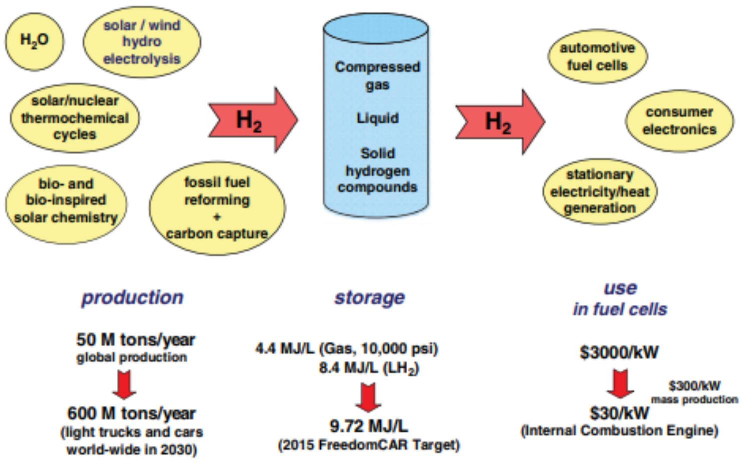

FIGURE 2 Hydrogen Fuel Alternative (Adapted from Dresselhaus 2008.)

The most efficient use of hydrogen is to convert its chemical energy into electrical energy in fuel cells. Fuel cells have a conversion efficiency of up to 60 per cent, making them more attractive than other fossil-fuel-based alternatives to electricity generation, with an average efficiency of about 34 per cent. The high efficiency of the motor (usually well over 90%) makes the fuel cell-motor combination more attractive for transportation than the gasoline engine, usually about 25% efficiency. (Özdemir & Unland 2015.) This potential for efficient end use adds an additional attraction to the environmental argument for hydrogen: It is not only free of pollutants and greenhouse gases, but also uses relatively little primary energy.

The current generation of fuel cells costs 100 times as much as a gasoline engine; in mass production, the cost differential could be reduced to 10 times. (Huggins 2016.) In addition to cost, life, maintenance frequency, and cold weather performance fuel cells in transportation applications do not yet have the ability to compete with gasoline engines. It is a challenge to reduce the cost and improve the performance of Cathode electrolyte membrane and catalyst of fuel cell. (Hashimoto 2019.)

Hydrogen storage for transport is a major material research challenge, namely to find a storage medium that combines hydrogen density greater than liquid density with fast kinetics to allow fast charging and discharging. Many traditional bulk materials have been explored and rejected as storage media because they do not meet these standards. However, nanoscience offers new opportunities to address this challenge because of its potential for high surface area and hybrid structures that can achieve multifunctional properties. (Dresselhaus 2008.)

Other attractive avenues for hydrogen development are electricity for personal electronic devices and emergency power supplies. In both cases, its performance is more important than its cost, and portable fuel cells have an advantage over batteries and fossil fuel powered generators. Fuel cells work longer between refueling and charging than batteries of the same weight and volume. For emergency power, hydrogen fuel cells are much more efficient than small fossil-fuel-powered generators. (Veziroglu 2007.)

Hydrogen fuel cells are moving parts that do not require lubrication and maintenance when not in use. Large-scale equipment can be stored in key locations such as hospitals or trucked to communities. As with utility-scale power generation, these personal electronics and emergency power applications do not need to address production and storage challenges prior to deployment. The relative cost of portable fuel cell power generation may be higher than that of batteries or fossil fuel alternatives, but the cost differences are small, so advantages such as size, charging time, efficiency and convenience may be decisive. (Westenberger 2016.)

By 2050, global energy demand is expected to double, electricity demand to triple and environmental and climate problems to intensify. This unique convergence trend has created many opportunities for hydrogen to enter the global energy structure as a complementary energy carrier and a natural partner for electricity. Hydrogen and fuel cells work well in a variety of areas, including the personal, automotive, neighborhood and utility sectors. Hydrogen connects chemical and electrical energy, making it more flexible, efficient, and clean than fossil fuels. These advantages will become increasingly important in the transition to new sources of energy and new uses in the middle of this century. (Singla, Nijhawan & Oberoi 2021.)

7 CONCLUSION

The article outlined the advantages and disadvantages of hydrogen fuel and in various fields of application and hydrogen fuel innovation and development. People know that it will be a long time before the use of hydrogen fuel is widely spread and popularized, and there will be many difficulties in the process, such as the storage and transportation of hydrogen, but with the development trend of the world's scientific and technological level, the authorities have a lot of tools at their disposal.

In addition to technical and economic factors, safety also plays an important role in the development of hydrogen fuel. For gasoline and electricity, the high energy density of hydrides has the potential to cause harm to people and property. Codes and standards for safe and reliable handling of hydrogen gas need to be developed. As hydrogen becomes more common, these regulations and standards need to be widely disseminated to professional hydrogen workers and the general public. This requires a concerted effort to educate people about the dangers of hydrogen and the safety procedures for handling it. Gasoline and electricity have similar dangers, but regulations, standards and education have effectively reduced the harm caused by these sources and carriers to acceptable levels. (Hashimoto 2019.)

Hydrogen like other fuels does have dangerous properties. But the public's fear of hydrogen seems to stem largely from the fear of the unknown. In addition to its dangerous properties, hydrogen has a number of safety features. Many studies on the safety effects of hydrogen have shown that it does not appear to be more dangerous than gasoline, natural gas or other fuels, but just different. Considering flame temperature, explosion energy and flame emissivity of hydrogenit is considered that hydrogen is safer than methane and gasoline.

The previous discussion indicates that hydrogen may play an important role as an energy carrier in the future. The road from the present to the future can be divided into three eras. The world is on its way from the "fossil fuel era" to the "hydrogen era" in which the fossil fuel and electricity are the main energy carriers.There are only two main energy carriers in this era: hydrogen and electricity. A "transitional era" would link fossil and hydrogen fuels.The gradual replacement of fossil fuels with chemicalfuels will become the property of the transition period.

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