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Hydrogen as the Future Sustainable Energy – A Review

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ABSTRACT

Nowadays, worldwide faces problems caused by fossil fuels such as urban air pollution and climate change. Hence, alternative energy sources are being searched in order to replace the fossil fuels. One of these alternative energy sources is coming from hydrogen. Hydrogen is the simplest and most abundant element in the universe and as a matter of fact hydrogen can be produced in variety of ways, including electrolysis of water, thermo catalytic reformation of hydrogen-rich organic compounds, and biological processes. This paper discussed mainly on the way of hydrogen being produced, its economic and environmental impacts to the society. Alternative sources of producing hydrogen as opposed to conventional method were also discussed.

1. Introduction

Over millions of years ago, plants covered the earth, converting the energy of sunlight into living tissue, some of which was buried in the depths of the earth to produce deposits of coal, oil and natural gas (Rosen et al., 2008). During the past few decades has found many valuable uses for these complex chemical substances, manufacturing from them plastics, textiles, fertilizers and the various end products of the petrochemical industry (Rosen et al., 2008). Nowadays, global economy, especially development country was highly depending on the fossil fuel. Main sector like transportation, electricity all need the fossil fuel to generate. While global is getting addicted to the fossil fuel, the side effect of it is getting worst fro day by day. Nitrogen oxides (NOx) in combination with volatile organic compounds (VOCs) cause the formation of ground level ozone and smog (Abdeen Mustafa Omer, 2006). This smog may highly effect human health and decrease the function of lung, while carbon monoxide may affect the red blood cell in transferring oxygen in human body. There is strong scientific evidence that the average temperature of the earth's surface is rising. This was a result of the increased concentration of CO_2 and other GHGs in the atmosphere as released by burning fossil fuels. Therefore, effort has to be made to reduce fossil energy use and to promote green energies, particularly in the building sector. Energy use reductions can be achieved by minimizing the energy demand, by rational energy use, by recovering heat and the use of more green energies. The adoption of green or sustainable approaches to the way in which society is run is seen as an important strategy in finding a solution to the energy problem. The key factors to reducing and controlling CO_2, which is the major contributor to global warming, are the use of alternative approaches to energy generation and the exploration of how these alternatives are used today and may be used in the future as green energy sources (Abdeen Mustafa Omer, 2006). Considering the benefits of green energy, sustainability of green energy supply and progress is assumed to be a key element in the interactions between nature and society.

Sustainable development requires a supply of energy resources that is sustainable available at reasonable cost and causes no or minimal negative societal impacts (Granovskii et al., 2006). Energy resources are essentially used to satisfy human needs and improve quality of life, but may generally lead to environmental impacts. Reduced CO^2 emissions can be achieved directly via increased efficiency, reductions in the fossil fuel component of the energy mix and the introduction of alternative energy sources (Rosen et al., 2008). Although in the past fossil fuels were prime in meeting the energy needs, the current global picture does not allow any further potential use. So, there is an urgent need to switch to sustainable energy carriers, such as hydrogen (Midilli and Dincer, 1997). Each Country has set up own National Green Technology Policy. The policy includes increase of the research and development activity on green technology, and increase of local production of green technology (Midillia et al., 2005). The establishment of the policy will result in more stable and effective in implement green technology to private and government sector. Worldwide energy policy promotes the development of modern sustainable energy communities (Chen et al., 2007). This policy improves the country's energy autonomy and financial independence from fossil fuels, subsequently forming an environment-friendly, eco-touristic profile (Papadaki et al., 2003).

2. Green Energy From Hydrogen

Hydrogen is defined as an attractive energy carrier due to its potentially higher energy efficiency and low generation of pollutants, which can replace conventional fossil fuels in the future. Hydrogen, as a renewable and green alternative energy sources, has been attracted extensive attention worldwide. It can be not only used for machinery with zero emission, but also for high thermal efficient hydrogen fuel cells. It acts in accord with increased regulatory environmental protection policies (Guo et al., 2009). Hydrogen is a non-toxic, clean energy carrier that has a high specific energy on a mass basis (e.g., the energy content of 9.5 kg of hydrogen is equivalent to that of 25 kg of gasoline (Ultanir et al., 1997).) Hydrogen has been identified as a potential alternative fuel as well as an energy carrier for the future energy supply. Hydrogen is clean and, in practice, it can be produced from water, which is abundant. Hydrogen is also renewable when it is produced from renewable energy sources. When it is converted into useful energy in the form of electricity via a fuel cell, the by-product is harmless water vapor. For comparison among different fuels, hydrogen has the highest energy content. As a result, hydrogen energy is indeed an ideal energy carrier in the future. In the United States, Australia, Germany, Japan, and many other countries, researchers and government officials have realized the vision of hydrogen economy. In Hong Kong, it is essential to evaluate the feasibility of hydrogen economy for better planning for future energy supply. As stated previously, hydrogen is only renewable and clean when it is produced from clean, renewable energy sources. Hydrogen production technologies and useful sources of renewable energy are reviewed for their latest development, followed by an evaluation of their integration for renewable hydrogen production to supply energy in Hong Kong (izumiya et al., 1998). Hydrogen energy is becoming increasingly important as recent technology progress makes hydrogen a realistic energy option. It is a long-term energy option, which means one of ''fuels of the future'' for buildings, transportation, portable application, vehicles and propellant for space mission, etc. Hydrogen can be used as a storage medium for intermittent and seasonal renewable technologies. It is also used for upgrading many metallurgical processes, as well as a chemical in different kind of industries, like synthesis of ammonia, methanol, oil refinery processes, etc. (Dragica et al., 2003). Its energy density is high, making it a high-efficiency energy source that can be used for transportation, heating and power generation. Hydrogen is also ideal from an environmental standpoint—it burns without emitting air pollutants. Efficient, clean, abundant and renewable— hydrogen is clearly the energy source to power the world. Hydrogen is abundantly present in Nature—nearly 75% of the mass of the Universe and 1% of the earth's crust is made up of hydrogen (Viswanath, 2004). Hydrogen energy is expected to be useful as secondary energy in the near future (for example, (Guo et al., 2009; Gonzalez et al., 2004)), applicable to fuel for vehicle and rocket, chemical use, Ni–H_2 electric cell, thermal engine using hydrogen storage alloys, direct combustion for heat, and so on. In addition, hydrogen energy can be used to build up dispersive energy system together with electric power by using water electrolysis and fuel cell. Use of hydrogen as an alternative fuel is gaining more and more acceptance as the environmental impact of hydrocarbons becomes more evident. Use of wind, hydropower and solar thermal energy for the production of hydrogen are the most environmental benign methods. The benefits and the drawbacks of the competing hydrogen production systems are presented (Koroneos et al., 2004).

3. Production of Hydrogen

Hydrogen can be produce in variety ways, including electrolysis of water, thermo catalytic reformation of hydrogen-rich organic compounds, and biological processes. The main fossil-fuel-based processes are steam reforming and catalytic decomposition of natural gas, partial oxidation of heavy oil and coal gasification. The principle non-fossil-fuel-based processes are water electrolysis, thermochemical cycles and photochemical, photoelectrochemical and photobiological processes (Marchetti, 2006), (OECD, 2006). Although steam reforming of natural gas, coal gasification and water electrolysis are the most important industrial processes for hydrogen production today (Bose and Malbrunot, 2007), (Dunn, 2002), thermochemical water decomposition is anticipated to play a significant role in hydrogen production in the future (Petri et al., 2006). Currently, H_2 is produced, almost exclusively, by steam reformation of methane or by water electrolysis. Biological production of H_2 (biohydrogen), using microorganisms, is an area of technology development that offers the potential production of renewable H_2 from biomass. Thermo catalytic processes for H_2 production include steam reforming, ''supercritical water'' partial oxidation, and gasification. There are still many ways to produce hydrogen, for example Hydrogen fuel for fuel cell vehicles can be produced by using solar electric energy from photovoltaic (PV) modules for the electrolysis of water without emitting carbon dioxide or requiring fossil fuels (Thomas and Nelson, 2008). Solar hydrogen projects have often consisted of power gridtied systems, in which PV modules were connected to an inverter to produce AC current which was then fed to the power grid. Power was taken from the grid through an independent circuit and converted to DC current to operate an electrolyzer and produce hydrogen.

4. Water Electrolysis

Electrolysis is defined as a process where electric current pass through a substance and causes chemical reaction, which will result in gain or loss in electron of the substances. Electrolysis consists of electrode, electrolyte, and electric current. Conventional water electrolysis, such as an alkaline water electrolysis, high-pressure electrolysis, and solid polymer electrolyte water electrolysis, is basically applied to produce hydrogen if a cheap source of electricity is available. In the alkaline water electrolysis, the cells use aqueous solutions of KOH, NaOH or NaCl as the electrolyte. This technology is well developed but the overall hydrogen production efficiency is too small, about 27% (Hefner, 1999). When the electrolysis is conducted at high pressures, the produced hydrogen gas is compressed at around 120–200 Bar (1740–2900 psi) (Youngjoon Shin et al., 2006). By pressurizing the hydrogen in the electrolyze the need for an external hydrogen compressor is eliminated, the average energy consumption for internal compression is around 3% (Ghosh et al., 2003).

4.1. Hydrogen production by water electrolysis

Production of H_2 by water electrolysis relies on passing an electric current through a conductive electrolyte in water (alkaline or polymeric), which results in splitting water molecules into H_2 and oxygen (O_2). Hydrogen produced by electrolysis of water is of relatively high quality, as no carbon, sulphur, or nitrogenous compounds are generated in the process. Purification costs for fuel cell grade H_2 are thus much less than for SMR. Electrolysis by itself is emission free, but lifecycle emissions are a direct function of the source of the electricity used in the process (David, 2009). In this context, water electrolysis is envisaged as an important source of zero emission hydrogen in the future (Gonzalez et al., 2004; Kruger, 2005). Why choosing water as sources to produces hydrogen gas? Water is the most promising candidate for hydrogen resource because it contains more hydrogen (111 kg/m3) and it can be regenerated in fuel cell as a result of hydrogen ignition. Generate hydrogen using carbon compounds may recede to the background mainly due to cogeneration of carbon dioxide, a greenhouse gas, as a by-product. In such a scenario, hydrogen production through water will become a reality. In this hydrogen economy, water is the raw material as well as the end product after converting the hydrogen stored energy into useful work (Viswanath, 2004). Water electrolysis is a very important technology for a large scale of hydrogen production. In such an energy system, water electrolysis will become a key technology, and high performance of water electrolysis should be achieved (Nagaia et al., 2009).

4.2. Hydrogen generation from water electrolysis—possibilities of energy saving

Hydrogen production via electrolysis of water from alkaline aqueous electrolytes is a well-established conventional technology. However, due to high energy requirements of about 4.5–5 kWh/m3n H_2 in most industrial electrolysers, the cost of hydrogen produced in such a way is high. Two types of activators, both ethylenediamine complexes of cobalt, were used separately or in combination with some molybdates. The activation energies were significantly decreased in the presence of single ionic activators. However, the best results regarding the activation energy reduction were obtained when combinations with the molybdate were used. [18]

4.3. A patent for generation of electrolytic hydrogen by a cost effective and cheaper route

Electrolysis of water has been studied using polished platinum as electrodes in a divided electrolytic cell. The cell is divided into two compartments using a chemically treated disc separator. The separator allows only the current to pass through and does not permit the ions to move from one compartment to the other. this set-up it has been demonstrated that water can be split into hydrogen and oxygen at as low a potential as 1:0 volt (Viswanath, 2004).

4.4. Types of Water Electrolyzes Available in the Industry

Water electrolysis is currently the most dominant technology used for hydrogen production from renewable sources because of high energy conversion efficiency. Water, used as a feedstock, is split into hydrogen and oxygen by electricity input. There are three types of water electrolyzes available in the industry: (1) alkaline electrolyze, (2) proton exchange membrane (PEM) electrolyzes, and (3) solid oxide electrolyze (Mitsugi et al., 1998; Rosen, 1995; Kreuter and Hofmann, 1998; Srinivasan and Salzano, 1977).

4.5. Disadvantage of Electrolytic Hydrogen

The main problem with electrolytic hydrogen is the high cost and energy consumption, which is directly proportional with cell voltage used to operate the electrolyzes. In order to make this technique more efficient and economical, the decreasing of the over potentials of the electrode reactions as well as by selecting inexpensive electrode materials with good electro catalytic activity are needed (Ramazan et al., 2009). Water electrolysis technology has more than one route, viz. conventional alkaline electrolysis, advanced water electrolysis, hot or high-temperature electrolysis and integrated electrolysis using solar or wind power. At present, the cost of hydrogen production increases in the order SRM high-temperature electrolysis advanced water electrolysis conventional electrolysis (Viswanath, 2004).

5. High Temperature Electrolysis

A very high temperature gas-cooled reactor (VHTR) can be effectively used for hydrogen production through several CO_2-free alternative technologies. High temperature electrolysis offers several advantages, such as:

(1) The amount of thermodynamic
electric energy required could be reduced and
(2) The electric current density would be increased due to a relaxation of the activation barriers at the electrolyte surfaces

Operation at high temperature reduces the electrical energy requirement for the electrolysis and also increases the thermal efficiency of the power-generating cycle (Emonts, 2001). Thus, hydrogen generation through high temperature steam electrolysis (HTSE) using solid oxide electrolysis cells (SOEC) has recently received increasingly international interest in the large-scale, highly efficient nuclear hydrogen production field. In the past three years, the research team mainly focused on preliminary investigation, feasibility study, equipment development and fundamental research (Shin et al., 2007). The high-temperature electrolysis (HTE) of water at 1100–1250K is typically accomplished using yttria-stabilized zirconia (YSZ) as an electrolyte (Yu Bo et al., 2009). The reactions occurring in a HTE process are shown below (Dutta et al., 2009):

Cathode: $H_2O + 2e^- \rightarrow H_2 + O_2^-$ (1)
Anode: $O_2^- \rightarrow 12O_2 + 2e^-$ (2)

6. Affect of Electrode to the Electrolysis

The voltage needed to realize water electrolysis consists largely of reversible potential (=1:23 V at 1 atm; 25◦C), solution (LeRoy et al., 2009). On purpose to realize good efficiency of water electrolysis, research which are being conducted so far are mainly focusing on the decrease of reversible potential and over voltage by realizing water electrolysis under high temperature and pressure or developing new electrode materials (Abe et al., 1984). However, little attention has been paid to ohmic loss in aqueous solution from hydrodynamic and two-phase Gow point of view. LeRoy et al. (2009) pointed out that the increase of volume fraction of hydrogen or oxygen bubbles between electrodes, i.e. increase of void fraction, and would cause the increase of electric resistance in aqueous solution, resulting in efficiency decrease of water electrolysis. Funk and Thorpe (1969) presented an analytical model of void fraction and current density distributions between electrodes, from view point of two phases Gow. Hine and Sugimoto (2009) obtained detailed information on void fraction, rising velocity and diameter distributions of bubbles. Bongenaar-Schlenter et al. (1985) measured void fraction and current density distributions, and proposed a “bubble diffusion model” for ohmic resistance between electrodes. Janssen and Visser (1991) also measured void fraction, ohmic over voltage on electrodes, and ohmic loss in aqueous there is an optimum condition of hydrogen production in water electrolysis.

6.1. Ionic Liquid as Electrolytes

Electrodes constructed with different electroactive materials such as platinum (Pt), nickel (Ni), 304 stainless steel (SS) and low carbon steel (LCS) have been tested in water electrolysis using 1-*n*-butyl-3-ethylimidazolium tetrafluoroborate (BMI.BF4). The highest j values obtained with Pt, Ni, SS and LCS electrodes were 30, 12, 10 and 42mAcm−2, respectively, and all efficiencies were in the 85–99% range. Water electrolysis reaction since the LCS electrode gave j and efficiencies as high as those observed with platinum electrodes (Roberto et al., 2006).

6.2. Titanium dioxide (TiO_2)

Titanium dioxide (TiO_2) is the most preferred material for the photo-electrode in hydrogen production by photo-electrochemical water-splitting. It is because of its:

i) high resistance to corrosion and photocorrosion in aqueous media,
ii) cheap and easy availability,
iii) environmental friendliness,
iv) energy band edges which are well-matched with the redox level of water,
v) electronic properties that can be varied by just changing the lattice defect chemistry or the oxygen stoichiometry (Bak et al., 2002).

However TiO_2, having an energy band gap of about 3.2 eV, mostly absorbs the ultraviolet portion of the solar spectrum and only a small amount of visible light (Fujishima, 2008). Thus, for efficient photocatalytic activity it is necessary to extend the photo-response of TiO2 to the visible spectrum by modification of its optical properties. Another problem is the high recombination rate of photo-generated electron–hole pairs which can be limited by introducing charge traps for electrons and/or holes, thus prolonging the recombination time. Many methods have been proposed to solve these problems, but doping TiO2 with foreign ions is one of the most promising strategies for sensitizing TiO2 to visible light and also for forming charge traps to keep electron–hole pairs separate.

6.3. Proposal for a new system for simultaneous production of hydrogen and hydrogen peroxide by water electrolysis

Experimental apparatus of the system is composed of a hydrogen electrode with platinum meshes, a hydrogen peroxide electrode with carbon material and an electrolyte with NaOH. In this paper, the superiority of the system is outlined, and the experimental results of the electrolytic synthesis of hydrogen and hydrogen peroxide from water are reported. Hydrogen peroxide is synthesized at the high efficiency when some kinds of carbon material are used as the hydrogen peroxide electrode (Andoa and Tanaka, 2009).

7. Environmental and Economic Aspects of Hydrogen Production and Utilization in Fuel Cell Vehicles

Three technologies for hydrogen production are considered here: traditional hydrogen production via natural gas reforming, and the use of two renewable technologies (wind and solar electricity generation) to produce hydrogen via water electrolysis, that is shown decrease of environmental impact and more advantageous for mitigating greenhouse gas emissions and traditional natural gas reforming is more favorable for reducing air pollution. (Mikhail Granovskii et al., 2006).

8. Ammonia as a Green Fuel and Hydrogen Source for Vehicular Application

Ammonia, mostly known as a nitrogen feedstock for agriculture or as a refrigerant, has been occasionally used in the past as fuel for internal combustion engines and fuel cells. Because it is a carbon-free substance and has high octane number there is currently a renewed interest for using ammonia as a fuel. The potential benefits and technical advantages of using ammonia as a sustainable fuel for power generation on vehicles are analyzed here based on some performance indicators including the system effectiveness, the driving range, fuel tank compactness and the cost of driving. The cooling effect of ammonia is another advantage and is included in the efficiency calculations. Cooling with ammonia represents up to 20% from the engine's power, being thus a valuable side benefit of ammonia's presence on-board allowing for downsizing of the engine cooling system and obtaining some air conditioning. If the cooling effect is taken into consideration, the system's effectiveness can be improved by ~11%. It is shown that a medium size hydrogen car converted to NH_3 becomes more effective per driving range cost at CN$3.2/100 km and fuel tank compactness with 18 L/100 km with a cost of ammonia assumed to be CN$0.3/kg (Zamfirescu et al., 2009). Some advantages of ammonia with respect to hydrogen are less expensive cost per unit of stored energy, higher volumetric energy density that is comparable with that of gasoline, easier production, handling and distribution with the existent infrastructure, and better commercial viability. Here, the possible ways to use ammonia as a sustainable fuel in internal combustion engines and fuelcells are discussed and analysed based on some thermodynamic performance models through efficiency and effectiveness parameters. If the cooling effect is taken into consideration, the system’s effectiveness reaches 46% implying that amedium size car ranges over 500 kmwith 50 l fuel at a cost below$2 per 100 km. The cooling power represents about 7.2% from the engine power, being thus a valuable side benefit of ammonia’s presence on-board (Zamfirescu et al., 2008).

9. Conclusions

Government and industry, keeping one foot in the hydrocarbon economy, are pursuing an incremental route, using gasoline or methanol as the source of the hydrogen, with the fuel reformed on board vehicles. A cleaner path, deriving hydrogen from natural gas and renewable energy and using the fuel directly on board vehicles, has received significantly less support, in part because the cost of building a hydrogen infrastructure is widely viewed as prohibitively high (Dunn, 2002). Yet a number of recent studies suggest that moving to the direct use of hydrogen may be much cleaner and far less expensive. Just as government played a catalytic role in the creation of the Internet, government will have an essential part in building a hydrogen economy. Research and development, incentives and regulations, and partnerships with industry have sparked isolated initiatives. But stronger public policies and educational efforts are needed to accelerate the process. Choices made today will likely determine which countries and companies seize the enormous political power and economic prizes associated with the hydrogen age now dawning.

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