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Hydrogen as energy source to avoid environmental pollution

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RESUMEN

El hidrógeno como energético para el futuro fue propuesto hacia fines de los años setenta. La razón principal fue la crisis petrolera, la cual llevó a considerar la necesidad de la substitución de los hidrocarburos por fuentes alternas de energía. El hidrógeno como fuente de energía, no sólo es el elemento más abundante en el universo, también es muy común en la Tierra. Es la fuente de energía alterna más importante para la creciente demanda energética y la respuesta para la necesidad actual de una energía limpia, eficiente y tecnológicamente amigable con el ambiente. Al quemar hidrógeno se produce agua y óxidos nitrosos, los cuales pueden ser eliminados utilizando celdas de combustible. Una celda de combustible es un sistema electroquímico que genera electricidad en una forma silenciosa y eficiente. Si a partir de una fuente de energía primaria que no produzca CO_2, como la solar, eólica o nuclear, se obtiene el hidrógeno, durante la generación de la energía se puede evitar la contribución al efecto invernadero y la lluvia ácida. El hidrógeno puede también ser utilizado como un portador de energía. Se presenta el estado del arte en investigación y desarrollo del uso del hidrógeno en México y en el mundo.

PALABRAS CLAVE: Contaminación ambiental, energía, almacenamiento y transporte de hidrógeno, celdas de combustible, fisión.

ABSTRACT

Hydrogen was proposed in the seventies as an energy source for the future. The main reason for the proposal was the petroleum crisis, which called attention to alternative energy sources and the necessity of hydrocarbon substitution. As an energy source, hydrogen is the most abundant element in the universe and is also common on earth. Hydrogen is the most important alternative energy source for the growing energy demand and is the answer to the present need for clean, efficient and environmentally friendly energy technologies. Burning hydrogen produces water and a small amount of nitrogen oxides, which can be eliminated with fuel cells. A fuel cell is an electrochemical device that produces electricity without combustion in an efficient and silent manner. If the hydrogen is obtained from a primary CO_2 free energy source, such as solar, wind or nuclear, the green-house effect and the acid rain could be avoided during energy generation. Hydrogen can also be used as an energy carrier. The state of the art in research and development on hydrogen worldwide and in Mexico is presented.

KEY WORDS: Environmental contamination, hydrogen energy, storage and transportation, fuel cells, fusion.

INTRODUCTION

Hydrogen was discovered by H. Cavendish in 1766; he concluded that water was not an element but was formed by hydrogen and oxygen. The name "hydrogen", which means "water former" in Greek, was proposed by A.L. Lavoisier in 1783. This highly reactive element, the first one in the periodic table, has two isotopes, deuterium and tritium. Hydrogen is the most abundant element in the universe and the third one in the earth's surface where it occurs as a diatomic molecule or combined with other elements; 70% of the existent hydrogen is found in water and in organic matter. Since the beginning of the 19th century, scientists have recognized hydrogen as a potential source of energy; it is known that hydrogen could be used as a primary energy source if the nuclear star reactions of hydrogen isotopes could be reproduced in magnetic containers. In fact, the energy of nuclear fusion is currently under research and development and an ambitious program in this field has been launched: the International Thermonuclear Energy Reactor (ITER). This new energy source is characterized by advantageous safety characteristics, almost unlimited fuel resources and low environmental impact. In long term, fusion reactors offer the potential for replacing fossil energies (Aymar, 2001)

As a secondary energy source, hydrogen could be obtained using a primary energy source followed by electrolysis (Kreuter and Hoffman, 1998), thermochemical cycles (Funk, 2001) or biomass (Das and Veziroglu, 2001) to produce hydrogen. Its direct burning forms small amounts of nitrogen oxides, but when fuel hydrogen is converted to electricity through an electrochemical process in a fuel cell, it only produces water as a sub product preventing environmental pollution. One of the problems concerning the use of hydrogen as an energy source is its acceptance by the public, the main point being safety, particularly because of accidents which occurred during the last century, the most striking one being the Hindenburg, the German airship explosion in 1937 when 36 people were killed. An investigation published by NASA concluded that the paint used on the zeppelin cover was the cause of the accident rather than hydrogen (Bain and Van Vorst, 1999). Today hydrogen is as safe as other fuels. In 1997, a study by the Ford Motor Company concluded that, with the proper engineering, the safety of a hydrogen fuel cell vehicle would be potentially better than a gasoline or propane vehicle.

Environmental pollution from fossil fuels produces inorganic and organic contaminants, such as sulfuric and nitric acids which affect life, as well as CO_2, the main contributor to global warming (Ogden, 1999). Particulate matter pollution to the atmosphere is also a product of fossil fuel burning. The future availability of oil indicates that the best oil fields have already been discovered; moreover new oil fields will increase the production cost.

METHODOLOGIES

Fuel cells

Hydrogen has the advantage to generate electricity when combined with oxygen to produce water. Figure 1 shows the cycle for hydrogen energy. A fuel cell is an electrochemical device, where hydrogen or other fuels can be converted to electricity using an electrocatalyst; since this conversion is not limited by the Carnot cycle, the efficiency in the generation of electricity is higher than in conventional engines. Fuel cells operate at different working temperatures and could, therefore, be used in different applications at sites where stable and continuous electrical current is needed. Such is the case of hospitals, shopping malls, dwellings or transportation. Table 1 presents the main types of Fuel Cells together with the working temperature and their kind of fuel. If hydrocarbons instead of hydrogen are used as fuel, a small amount of CO_2 is formed.

In the past years several companies have been created to do research and development on fuel cell energy: Tokyo Electric Utility, Kansai Electric Power International Fuel Cells, Toshiba, Siemens/Westinghouse, Plug Power/GE, Fuel cell Energy Corp, EPRI, Ballard Power Systems and others. Furthermore Westinghouse Company has announced the marketing of a 1 MW solid oxide fuel cell power plant 70% efficient, which started to operate in 2001. A new member of the fuel cell family is the regenerative fuel cell, in which water is separated into hydrogen and oxygen by a solar-powered electrolyzer. The hydrogen and oxygen are fed into the fuel cell, which in turn produces electricity and water. The water

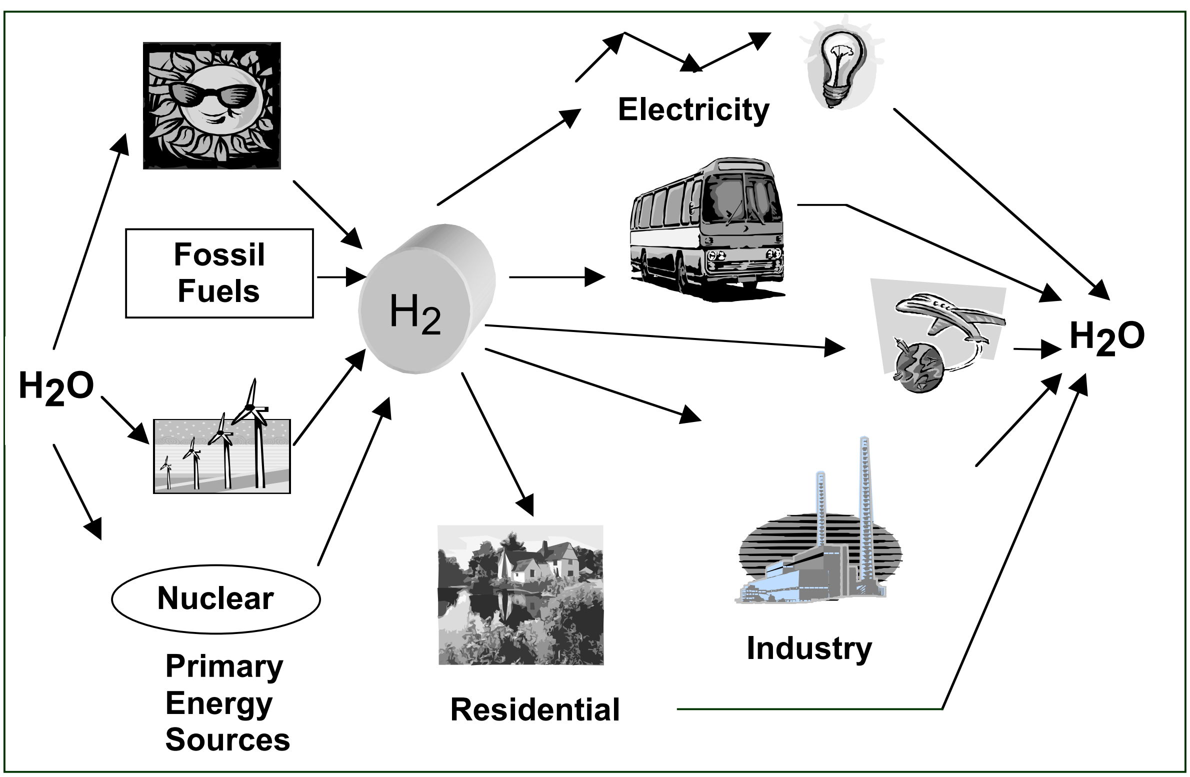

Fig. 1. Water can be separated using a primary energy source, then stored and used as energy carrier. The utilization of hydrogen produces energy and water, after which the cycle can be repeated.

Table 1

Main Types of Fuel Cells

Type	Operation temperature (°C)	Fuel	Comments
Phosphoric acid	170-210	Hydrogen Natural Gas Methanol	Most mature fuel cell technology. 200 kW up to 1Mw units
Molten Carbonate	650	Hydrogen Natural Gas Carbon Monoxide Landfill Gas	60% efficiency and with cogeneration 85% efficiency 10 kW to 2 MW units
Solid Oxide	800-1000	Hydrogen Natural Gas	Efficiency equivalent to molten carbonate. units up to 200 kW
Alkaline	60-90	Hydrogen	Efficiency up to 70% 220 kW units
Proton Exchange Membrane	80-90	Hydrogen Methanol	Primary options for light-duty vehicles 50 to 250 kW

is then recirculated back to the solar-powered electrolyzer where the process is repeated. The choice of an adequate fuel cell depends on its use.

Hydrogen production

Four hundred billion cubic meters of hydrogen are produced worldwide each year mainly at oil refineries or by electrolysis in chemical industries. At present, the most common and least expensive method to produce hydrogen is steam reforming. In this process methane (CH_4) or other hydrocarbon is heated over a catalyst and decomposed into hydrogen and carbon monoxide. If steam is added more hydrogen is produced and carbon dioxide is obtained as a subproduct (Astanovsky *et al.,* 1994).

Coal can be used for hydrogen production as well, but in this case the carbon dioxide produced needs to be sequestered. Sequestration is the deposition of the exhausted gases that have been produced in steam reforming or coal gasification, into depleted oil gas fields, deep coal beds or deep saline aquifers. Presently China, Italy and India have formal plans to cooperate in hydrogen production by gasification.

Hydrogen can also be extracted from oil, gasoline and methanol through reforming, but in these cases carbon sequestration technologies are required. In October 2000, BP and Ford donated $20 million to Princeton University to study the technical and economical viability of this approach.

Besides, hydrogen can be produced directly with sunlight and water by biological organisms (Das, 1998) or by using semiconductors-based systems. The use of non CO_2 hydrogen producing technologies such as wind, solar or nuclear can help to avoid global warming and environmental pollution.

Hydrogen storage and transportation

Hydrogen can be stored as compressed gas, as liquid hydrogen and as metal hydrides (Hanneken, 1999). Although some hydrides are commercial, studies on new alloys with better conditions of temperature and pressure storage are still needed. Research for hydrogen storage in carbon structures is currently under way worldwide. Table 2 shows the different methods of hydrogen storage together with their applications. In Kiev, Germany, the town gas which is composed of 60% hydrogen has been stored in a gas cavern since 1971. Gas de France has stored hydrogen-rich refinery products in an aquifer structure, and The Imperial Chemical Industries had stored hydrogen in salt mines caverns.

Hydrogen transportation depends on the needs. At present about 5% of the hydrogen produced is delivered as liquid or gas by truck or pipelines. In Table 3, the different

Table 2

Methods of Hydrogen Storage

Underground *	Large quantities Long term storage times
Liquid	Large quantities Long term storage times
Compressed Gas	Small quantities Short-term storage times
Metal Hydrides	Small quantities
Carbon structures	Small quantities

Table 3

Methods of Hydrogen Transportation

Method	**General use**
Pipeline	Large quantities and long distances
Liquid	Large distances
Compressed Gas	Small quantities over short distances
Metal Hydrides	Short distances

methods of hydrogen transportation with their general use are shown.

For hydrogen transportation, a 210-kilometer hydrogen pipeline has been operating in Germany since 1939. In the USA over 720 km of hydrogen pipelines are found along the Gulf Cost and around the Great Lakes. The longest hydrogen pipeline is found in Europe between France and Belgium.

International Standards

In 1990 the International Standards Organization in Geneva, Switzerland, decided to start formulating the international standards for hydrogen energy technology. The ISO/TC-197 Committee was established to draw up such standards. At the first meeting, the committee was set up with 10 sub-committees: Definitions, Measurements, Handling, Safety, Vehicles, Aerospace, Electro-chemical Devices, Hydrides, Environment and Applications.

In 1994, the secretariat was transferred to the Standards Council of Canada; at present the Normalization Bureau of Quebec is serving as the secretariat of the committee. The ISO/TC 197, which is committed to preparing the international safety hydrogen standards, comprises 12 participating countries and 15 observers and maintains communication with 10 organizations including 8 technical committees.

Research in the World and in Mexico

At present, hydrogen is mainly consumed on site for petroleum refining or for ammonium fertilizers, resins, plastics and solvent manufacture. Additionally hydrogen obtained through electrolysis is important in the alimentary industry. The amount of hydrogen used as an energy source, or as an energy carrier, to transport energy from the point of production to the point of utilization, is almost negligible. Nevertheless, several research and development projects on hydrogen energy are under way at the international level; a brief account of the major projects appears on Table 4 (Dunn, 2001). The financial support of USA for hydrogen projects is still 1/5 of the budget for the clean coal technologies, and only 1/10 of that for nuclear power.

The European Union is testing electrolyzers that operate with solar or wind energy for hydrogen production, making research in materials for fuel cells. Besides some fuel cell buses are already in use in Bavaria. In Japan, the WE-NET (World Energy Network) project has done research and development on fuel cells, hydrogen stations, metal hydride storage, thermo-chemical hydrogen production obtainead from the helium gas cooling of the High Thermo-Chemical Nuclear Reactor (HTGR), and cars working with fuel cells. Iceland wants to become the world's first hydrogen economy and a very ambitious multimillionaire project is under way. Germany has developed a project with Saudi-Arabia, Hy-Solar, to use solar energy for hydrogen production via electrolysis. Argentina wants to use the enormous potential of the Patagonia wind for the same purpose. Canada has very important projects on hydrogen production, storage and transportation, as well on fuel cells. Cuba has an incipient but interesting national hydrogen program. The International Energy Agency (IEA) has a hydrogen program with 13 participating countries: some of which are the following: Japan, USA, Canada, Italy, The Netherlands, Norway, Spain, Sweden and Switzerland. Researchers, industries, and users are working on regulations for the use of hydrogen.

In Mexico, the institutions doing research and development on hydrogen are the following: Instituto Nacional de Investigaciones Nucleares (ININ), Instituto de Investigaciones Eléctricas (IIE), and Instituto Mexicano del Petróleo (IMP), all of which are a part of the Secretaría de Energía (Energy Minister). Other research centers are: Centro

Table 4

Major Hydrogen Projects in the World

Region	Program or Number of Projects	Financial Support
United States	440	140 millions dollars per year for Federal Projects (27 of which go to basic research) and another 120 from academy and industry
The European Union	60 The Integrated Hydrogen Project	25 million dollars per year Co-financed with certain European countries.
Japan	WE-NET	17 million dollars by year
Iceland	First World Hydrogen Economy	Multimillion dollar program financed by government and private industry.
Germany	German Program Hy-Solar	Government, automotive industry and oil companies
Canada	Hydro-Quebec Euro-Quebec	Government, bankers, electricity and oil companies and automotive industry

de Investigación y de Estudios Avanzados (CINVESTAV), Instituto Politécnico Nacional (IPN) and Instituto Tecnológico de Monterrey (ITM) as well as Universidad Nacional Autónoma de México (UNAM), Universidad Autónoma Metropolitana (UAM), Universidad de las Américas (UA) and Universidad Autónoma de Zacatecas (UAZ). There are approximately 30 people working in all the fields related with hydrogen energy materials. The main studies under way deal with synthesis and characterization of: oxides to be used as anodes for electrocatalytic cells; semiconductors to be used as electrodes in solar electrolysers (López *et al.*, 2002, Arriaga and Fernández, 2002); mixed metal alloys for hydrogen storage (Palacios *et al.,* 2002); catalysts materials for fuel cells (Durón *et al.,* 2000) and power electrical generation. Likewise determination of the life cycle analysis of hydrogen fuel is in progress.

The researchers working on hydrogen are very interested in developing the infrastructure required for the application of hydrogen as a fuel; as a result of their interest and efforts, the Mexican Hydrogen Society was founded three years ago. The benefits of a Mexican hydrogen program can be grouped in four main areas:

a) Alternative energy sources for a growing energy demand.

b) An answer to the present need for clean, efficient and environmentally friendly energy technologies.

c) A better use of our natural resources, both renewable and non renewable.

d) A better knowledge of energy alternatives for energy strategies and policies.

CONCLUSIONS

In first world countries, projects for research, development and demonstration are in progress; in developing countries, only Saudi Arabia, Argentina and Turkey have international projects. In Mexico, most of the studies under way are on research materials for hydrogen production and storage, and on materials for fuel cells. We feel that a major integration with the world hydrogen communities is needed.

Furthermore, if the projects succeed in lowering the cost of hydrogen production and storage, and of fuel cells, and if people accept hydrogen use, the future renewable energy will be hydrogen energy, which will result in preventing environmental pollution.

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