American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-2, pp-13-17
www.ajer.org
Research Paper Open Access

# Hydrogen Production Using Renewable Energy

Muqbil Saleh Almuqbil
*AOI, Student Member, IEEE Electrical Engineering Department, University of South Florida, Tampa*

***ABSTRACT :*** *The energy challenges facing the world today are enormous. Therefore, the world needs sustainable energy resources to replace the finite conventional energy resources. Also, it is crucial to limit the environmentally harmful greenhouse gas emissions. This paper will review the production of hydrogen by water splitting using renewable energy resources such as solar, wind, and thermochemical energy. Splitting the water into oxygen and hydrogen gas can be done by passing an electrical current through the water. Clearly, using a sustainable resource to create the potential difference needed to split the water will increase the efficacy of the hydrogen energy. In addition, water can be split utilizing thermal energy to drive the chemical reaction to decompose water into hydrogen and oxygen.*
***KEYWORDS*** *Hydrogen production, water splitting*

---

## I. INTRODUCTION

All sorts of organisms need energy to live, grow, and reproduce. In addition to these rationales, humans consume much more energy as a consequence of their economic and social development. It was found out that societies need much more of energy to eliminate of poverty [1]. The amount of energy consumption noticeably increased since the beginning of the industrial revolution few centuries ago. Therefore, the need of renewable energy recourses is essential because of the finite amounts of the conventional energy recourses and the raising demand of energy. Furthermore, the negative environmental effects associated with the conventional energy recourses urge humans to alternate to more eco-friendly energy resources. Many environmental activists and energy scientists believe that the globe has only a few centuries before the catastrophe to make the transformation from a fossil fuel-based economy into a sustainable energy-based economy and that include the use of hydrogen as fuel [2]. At present, many countries around the world consider hydrogen as a strategic necessity in energy planning for the future. Hydrogen could be a supreme form of energy since it's a nonpolluting fuel with a capability of energy production and storage in integration with renewable technologies. Hydrogen is a basic element in earth. As a matter of fact, it is the most abundant element in the universe; it's light, tasteless and invisible gas that can be used as an eco-friendly energy fuel [2]. Hydrogen exists in nature mainly in water (H2O), but it could be artificially produced in number of methods. For example, it can be generated from fossil fuels by steam reforming, partial oxidation method, etc [3]. Additionally, several methods could be used to produce hydrogen by splitting the water H2O into H and O2 which will be discussed in this paper. After hydrogen is produced it needs, as any other product, packaging, transportation, storage, and transferring to the destination of use. Figure 1 shows the process of production and use of hydrogen. Liquefaction and compression are techniques that can used to package hydrogen then it is transported using vehicles or pipelines to destination of use [4]. The paper is organized as follow, an overview of hydrogen production is provided in section II. In Section III, water splitting using solar energy is discussed. An overview the use of wind and hydroelectric energies to produce hydrogen is presented in section IV. Section V and VI represent the thermochemical water splitting and water splitting by radiolysis, respectively. Finally, conclusion is summarized in section VII.

## II. PRODUCTION OF HYDROGEN

An essential issue with hydrogen is that it is not naturally present on our planet as a separate gas, so the main challenge for using it as fuel is how to extract it from those compounds where it exists. Current methods of extraction are economically and environmentally not quite efficient. It can be produ- ced from hydrocarbons, mainly natural gas, and it's extracted through a method called "reforming". Reforming can be performed on hydrocarbons to extract hydrogens. It is a chemical process which is, in essence, an energy conversion process.

In other words, the higher heating value (HHV) contained in hydrocarbons is transferred to the hydrogen's HHV. According to the current prices of energy, reforming of fossil fuels to produce hydrogen is much more cost effective than water electrolysis [4]. However, water electrolysis and other water splitting techniques have advantages over producing hydrogen by reforming fossil fuels. Solar splitting is the process of separating water H2O into hydrogen and oxygen molecules. There are many ways to split water and five different methods were discussed in this paper. Unfortunately, the process of hydrogen production is always associated with very large amounts of energy consumption which reduces the feasibility of these methods. However, in order to produce hydrogen in more sustainable way, there are technologies that provide the energy needed to produce hydrogen from renewable energy recourses.

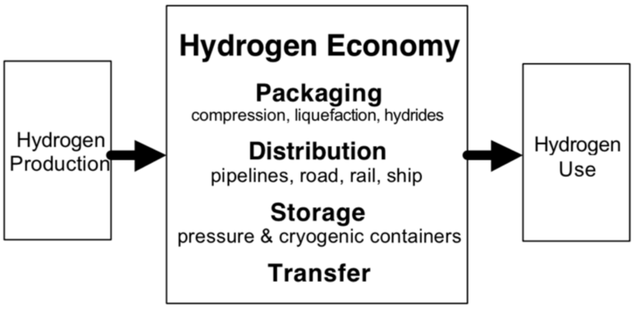


**Fig.1. Schematic Presentation of "Hydrogen Economy"**
**Adapted from "Energy and the hydrogen economy" by U, Bossel et al.**

## III. Solar Water Splitting

Solar water splitting is the process of decomposition of water H2O into H2 and O2 using solar energy by performing photocatalyst over a semiconductor. There are three main methods for solar water splitting: Photochemical (PC) system, photoelectrochemical (PEC) cell, and photovoltaic-electrolysis (PV-E), as shown in figure 2 [5].

**(a) PV-E method**

Photovoltaics + Electrolyzer is a method that combines two already existed technologies: photovoltaic (PV) cell and water electrolyzer. PV-E method have been proved with high solar to hydrogen (STH) conversion efficiencies over 10% [6–7]. However, this method is still can't compete with conventional technologies that use fossil fuel (e.g. steam reforming of natural gas) due to its elevated cost [8].

**(b) PC method**

The photocatalysis method is inexpensive and simple process. However, this approach has low STH efficiency which is typically at least one order of magnitude lower (<1%) [9]. In addition, PC approach has a potentially explosive mixture of hydrogen and oxygen which requires costly procedures to separate the H2 and O2 to avoid back reactions [9].

**(c) PEC method**

Photoelectrochemical cell (PEC) configuration consist of a semiconductor photoelectrode (either photoanode or photocathode) and a metallic electrode. PEC can accomplish lower overall system cost compared to PV-E method and also can become cost efficient compared to the existing fossil-fuel derived hydrogen if the efficiency and lifetime are substantially improved to >10% and >5 years, respectively [10–11].

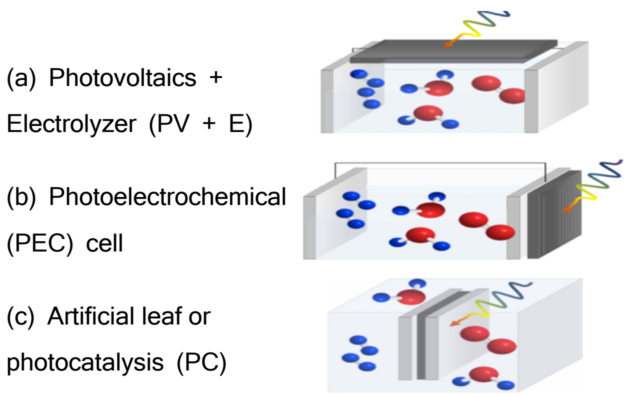


**Fig 2. Schematic Presentation of three types of solar water splitting system, Adapted from "ChemSusChem, 2017, 10, 1318-1336.**

## IV. WATER SPLITTING UTILIZING HYDROELECTRIC AND WIND ENERGY

Electrolysis is a type of chemical catalysis where water splitting is driven by passing an electrical current through water. The needed electrical current could be derived from a renewable resource such as hydroelectric power plant or wind power plant. The medium in which the reaction of water splitting take place is called electrolyzer. The electrochemical reaction can be described as [12]:

$$H_2O(l) + 237.2\left(\frac{KJ}{mol}\right)_{electricity} + 48.6\left(\frac{KJ}{mol}\right)_{heat} = H_2 + 0.5O_2 \qquad (1)$$

It should be noted that electrolyzers come in a range from small to large sizes which suites the application of large-scale hydrogen production projects. Based on the type of electrolyte material, electrolyzers are divided into three categories [13]:

**(a) ALKALINE ELECTROLYZERS**

Alkaline electrolyzer is the earliest electrolyzer to be developed back in 1789 by Peats van Troostwijk [14]. In Alkaline electrolyzer, hydroxide ions (OH-) are transported through the electrolyte from the cathode (where hydrogen is being generated) to the anode. A liquid alkaline solution of sodium or potassium hydroxide is used as the electrolyte. alkaline electrolyzers have less cost than the other types of electrolyzers. They are the most mature and common electrolysis technology [15].

**(b) SOLID OXIDE ELECTROLYZERS**

Solid oxide electrolyzer cells (SOEC) are the newest type of electrolyzers which was introduced back in 1980 by Donitz and Erdle [16]. The electrolyte of SOEC is a slide ceramic material. This electrolyte conducts selectively the negatively charged oxygen ions (anions) at high temperatures (900-950 oC). The anions are transferred trough the electrolyte and they reach to the anode where they convert into oxygen.

**(c) POLYMER ELECTROLYTE MEMBRANE ELECTROLYZERS**

PEM electrolyzer was introduced back in 1960s by Russel et al [17]. The electrolyte of PEM is a solid specific plastic material. In PEM, oxygen and positively charged hydrogen ions (protons) are formed by water reaction at the anode. Then the protons are transferred to the cathode where it receives electrons and forms hydrogen. These different electrolyzers could be coupled with a sustainable energy source to form a system that utilizes electricity derived from a renewable resource through the electrolyzer to produce hydrogen as discussed in the following.

**1. Hydroelectric Energy**

Hydroelectricity means to convert the energy from running water into electricity. It's considered a sustainable source of energy since the water cycle is always renewed by the sun. Like any other technology, hydroelectric energy has advantages and disadvantages. The cost of hydroelectricity power (that includes maintenance and labor) is low compared to other sustainable energy technologies. In addition, the start-up time of hydroelectric power plants is quite short as in a few minutes it would reach its full load capacity. On the other hand, hydroelectric power plants are not useful in the large dry parts of our planet where there is no much water available. An electrolyzer system can be combined with a hydroelectric power plant to produce hydrogen. An application of that has been built in Switzerland where 2% of the produced electricity is transferred to an electrolyzer. The hydro-electrolyzer system is located at a run-of-the-river site and it produces about 20,000 kg hydrogen per year [18].

**2. Wind Energy**

Wind energy converts the mechanical movement of the wind turbines into electricity. The initial cost of wind plants is high, but its power is relatively low compared to other renewable energy technologies. However, the intermittent nature of wind is a major drawback that affects the stability of the output power. A wind plant can be integrated with an electrolyzer system to produce hydrogen. Figure 3 represent an overview of the elements that consist a wind electrolyzer system

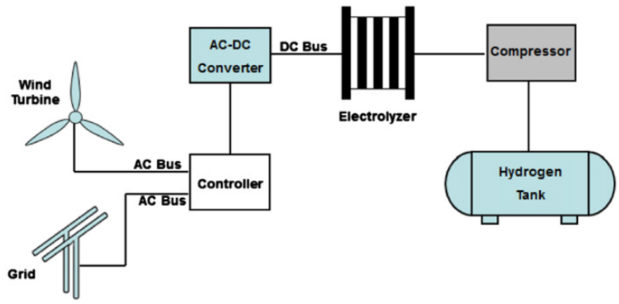


**Fig.3 Schematic presentation of overall wind electrolyzer system. Adapted from [19]**

An application of hydrogen production via wind energy was built in Turkey where the wind-electrolyzer system produces hydrogen in the range from 1665.24 kg H2 to 6288.59 kg H2 per year. These amounts of hydrogen are produced using a wind energy conversion system with 1300 kW rated power [19].

## V. Thermochemical Water Splitting

The technology of thermochemical water splitting utilizes thermal energy directly from the sun or the waste heat from different chemical reactions to produce hydrogen. The net reaction is [20]:

$H_2O$ + thermal energy → $H_2 + ½ O_2$ (2)

The general process of thermochemical water splitting requires both work and heat as an input as shown in figure 4 where water is split in the enclosed region using thermal energy.

It should be noted that the chemicals used in this process are reused with each cycle. Therefore, there is no waste of chemicals and the process consumes only water and produces only hydrogen and oxygen. Although this technology needs high temperature heat to drive the water decomposition reactions, the needed heat could be derived from sustainable resources such as concentrated solar thermal plants. Another option is to utilize the waste heat from different chemical reactions such nuclear power plant reactions. Generally, thermo- chemical water splitting technology produces hydrogen with no greenhouse gas emissions.

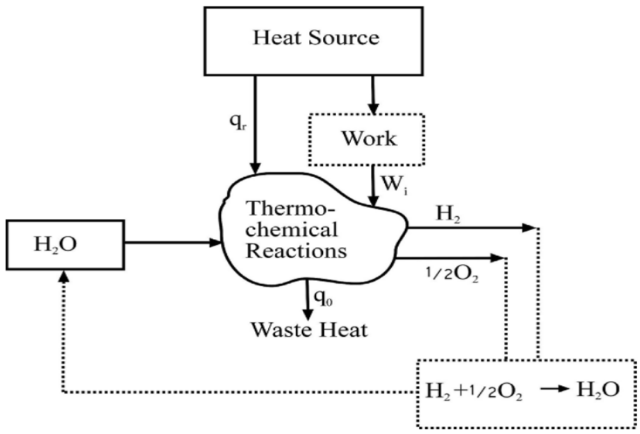


**Fig.4 Schematic presentation of overall thermochemical water splitting process. Adapted from [20]**

## VI. Water Splitting by Radiolysis

Another interesting way to make use of the radioactive waste of the chemical reactions associated with nuclear reactors is to utilize it to produce hydrogen via radiolysis. Water is used as a heat transfer fluid in nuclear power reactors and it's exposed to radiation from the core of the reactor. The radiation can decompose coolant water to produce oxygen and hydrogen peroxide [20]. The idea of splitting the coolant water by radiolysis to produce hydrogen was first introduced in the 1950's and received much attention since [21]. Number of species are produced when water is irradiated by the radioactive emissions depending on the nature and energy of the radiations. The elevated energy radiations/particles lose energy as they pass though water and eject high energy electrons from the atomic shells. Consequently, the high energy electrons cause further reactions of secondary lower energy electrons created by those higher energy electrons [20]. Hydrogen molecules (H2) and atoms (H) are examples of the important species produced by such a process. The technology of hydrogen production by water radiolysis aims to productively utilize nuclear waste emissions to produce another form of energy. Although, at least for today, it is not considered to have potential to play a competitive role among the other water splitting technologies due to the use of radioactive materials which could lead to contaminate the product stream [20].

## VII. CONCLUSION

A growing amount of energy is required in the world due to the economic and social development. It's been noticed through the centuries of human civilization that the availability of energy results reduction of poverty. As a result, energy consumption has been increasing. Conventional energy is relatively inexpensive. However, it is finite and has many negative environmental consequences. as a matter of fact, many of environmental activists and energy scientists believe that the world has only few centuries before the catastrophe to make the transformation from conventional energy into sustainable energy. Therefore, an urgent need for sustainable energy has been raising recently and many major nations around the world consider hydrogen economy in their strategic energy plans. Hydrogen is the most abundant event on earth, and it could be used as a fuel to replace conventional fossil fuel. However, an essential challenge of hydrogen economy that is hydrogen atoms do not exist separately in nature. However, hydrogen can be artificially produced from fossil fuels by reformation. In addition, hydrogen can be produced from water by splitting the h20 molecules into hydrogen and oxygen. The water splitting process is power hungry itself. So, utilizing a renewable energy resource to supply the required energy to splitting the water is a promising efficient way to produce hydrogen. The use of solar, wind, hydroelectric, thermochemical, and nuclear energy as renewable energy resources to produce hydrogen was discussed in this paper.

## REFERENCES

[1] Pimentel, Ph.D., D., Pimentel, M.S., M. H. (2007). Food, Energy, and Society. United Kingdom: CRC Press.
[2] Hoffmann, P. (2012). Tomorrow's Energy: Hydrogen, Fuel Cells, and the Prospects for a Cleaner Planet. (Second Edition,Revised ed.). Cambridge: The MIT Press.
[3] Dou, Y., et al. (2017). Opportunities and Future Challenges in Hydrogen Economy for Sustainable Development, Elsevier: 277-305.
[4] Bossel, U., & Eliasson, B. (2003). Energy and the hydrogen economy. Methanol Institute, Arlington, VA.
[5] Chu, Sheng; Li, Wei; Hamann, Thomas; Shih, Ishiang; Wang, Dunwei; Mi, Zetian (2017). "Roadmap on solar water splitting: current status and future prospects". Nano Futures. 1 (2): 022001.
[6] Luo, J., Im, J. H., Mayer, M. T., Schreier, M., Nazeeruddin, M. K., Park, N. G., ... & Grätzel, M. (2014). Water photolysis at 12.3% efficiency via perovskite photovoltaics and Earth-abundant catalysts. Science, 345(6204), 1593-1596.
[7] Jia, J., Seitz, L. C., Benck, J. D., Huo, Y., Chen, Y., Ng, J. W. D., ... & Jaramillo, T. F. (2016). Solar water splitting by photovoltaic-electrolysis with a solar-to-hydrogen efficiency over 30%. Nature communications, 7, 13237.
[8] Nowotny, J., Bak, T., Chu, D., Fiechter, S., Murch, G. E., & Veziroglu, T. N. (2014). Sustainable practices: solar hydrogen fuel and education program on sustainable energy systems. International Journal of Hydrogen Energy, 39(9), 4151-4157.
[9] Fabian D M, Hu S, Singh N, Houle F A, Hisatomi T, Domen K, Osterlohf F E and Ardo S (2015) Particle suspension reactors and materials for solar-driven water splitting Energy Environ. Sci. 8 2825
[10] Pinaud B A et al (2013) Technical and economic feasibility of centralized facilities for solar hydrogen production via photocatalysis and photoelectrochemistry Energy Environ. Sci. 6 1983
[11] Sathre R, Scown C D, Morrow W R, Stevens J C, Sharp I D, Ager J W, Walczak K, Houle F A and Greenblatt J B (2014) Life-cycle net energy assessment of large-scale hydrogen production via photoelectrochemical water splitting Energy Environ. Sci. 7 3264
[12] Grube T, Stolten D. (2010) Electromobility with fuel cells and batteries: advantages for the use of hydrogen. BWK Energie Fachmagazin 62(4):S16e7.
[13] Mohammadi, A., & Mehrpooya, M. (2018). A comprehensive review on coupling different types of electrolyzer to renewable energy sources. Energy, 158, 632-655.
[14] Trasatti, S. (1999). Water electrolysis: who is first?. Journal of Electroanalytical Chemistry, 476(1), 90-91.
[15] Ursua, A., Gandia, L. M., & Sanchis, P. (2011). Hydrogen production from water electrolysis: current status and future trends. Proceedings of the IEEE, 100(2), 410-426.
[16] Dönitz, W., & Erdle, E. (1985). High-temperature electrolysis of water vapor—status of development and perspectives for application. International Journal of Hydrogen Energy, 10(5), 291-295.
[17] Nuttall, L. J., Fickett, A. P., & Titterington, W. A. (1975). Hydrogen generation by solid polymer electrolyte water electrolysis. In Hydrogen Energy (pp. 441-455). Springer, Boston, MA.
[18] H2 Energy to generate green hydrogen from hydropower in Aarau (2016) Fuel Cell Bull 2016(7):8.
[19] Genç, M. S., Çelik, M., & Karasu, İ. (2012). A review on wind energy and wind–hydrogen production in Turkey: A case study of hydrogen production via electrolysis system supplied by wind energy conversion system in Central Anatolian Turkey. Renewable and sustainable energy reviews, 16(9), 6631-6646.
[20] GRIMES, C., VARGHESE, O., & RANJAN, S. (Eds.). (2007). Light, water, hydrogen: the solar generation of hydrogen by water photoelectrolysis. Springer Science & Business Media.