Green Hydrogen Production from Renewable Energy Sources

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Abstract - *Hydrogen plays a vital role in global energy transition acting as a clean energy carrier. The naturally available hydrogen cannot meet the present demand for cleaner energy sources. Thus, it serves the need to produce hydrogen through chemical processes. It can be obtained from various conventional and non-conventional energy sources. The production hydrogen from conventional energy sources such as fossil fuels and nuclear power results in greenhouse gas emissions. However, hydrogen produced from renewable energy sources such as solar energy, wind energy, biomass and geothermal energy results in zero carbon emission. Currently, countries are relying on renewable energy supplies due it's availability and low-cost hydrogen supply. This paper discusses the potential of clean hydrogen, methods of production of hydrogen using renewable energy sources such solar, wind and biomass, and benefits and limitations associated with hydrogen production.*

1. INTRODUCTION

The increase in the urgency for greenhouse gas emission and reduce in the cost of hydrogen supply from renewable have contributed to the growth of hydrogen in recent years. It is necessary to ensure low-cost clean hydrogen supply. The various source of production of hydrogen includes fossil fuel-based hydrogen production (grey hydrogen,); fossil fuel-based hydrogen production combined with carbon capture, utilization and storage (CCUS; blue hydrogen); and hydrogen from renewable (green hydrogen).

In the coming years, green hydrogen produced is projected to grow rapidly. Hydrogen production from renewable energy sources is technically viable with low emission rates. Hydrogen can expand the potential growth of renewable energy market and its industrial reach. Electrolyzers can add demand-side flexibility. For example, European countries such as the Netherlands and Germany are facing future electrification limits in end-use sectors that can be overcome with hydrogen [1]. Hydrogen can be used as energy storage in various situations.

2. POTENTIAL OF CLEAN HYDROGEN

Hydrogen has the potential of a new commodity that can be utilized in different ways in the market. The green hydrogen can be converted into synthetic natural gas and shipped to markets using existing infrastructure, and that natural gas can be converted into low-carbon hydrogen using SMR and CCS, offers a prospect for natural gas-producing countries [1]. The hydrogen production has a greater potential even in deserts as it can be produced using renewable energy sources. Thus, the countries that rely on fossil fuels for their national revenue benefit from conversion to a hydrogen economy as it offers new economic prospects. It also may assist to create new export opportunities for countries with prosperous renewable energy resources [1]. But every loss may arise during liquefaction stage for shipping of hydrogen. Another alternative is the conversion of hydrogen into other carriers, for example ammonia, methanol and liquid organic hydrogen carriers which may cause significant losses. These losses can be reduced by the utilization of hydrogen at the production site itself to manufacture clean products such as ammonia, methanol, DRI or e-fuels.

3. HYDROGEN PRODUCTION FROM SOLAR ENERGY

Using the various methods listed below the solar energy is utilized to produce hydrogen.

3.1. Thermochemical Process

The method involves the production of hydrogen through thermochemical process by splitting water in the presence of heat from the solar energy. When the heat alone is used for water splitting it is also called thermolysis. The water molecules can be directly splitted by thermal energy or indirectly with the help of chemicals. The process requires very high temperature to carry out the endothermic reaction. To achieve water decomposition, the temperature needs to be higher than 2000°C without using any chemicals. Hence chemical reactants or catalyst are used to lower the temperatures. In this case a two-step water splitting cycle take place in which metal oxide is dissociated and later react with water to produce hydrogen.

The general cycle consists of two steps:

Dissociation: $M_xO_y \rightarrow M_xO_{y-1} + 1/2\ O_2$ (1)

Water reduction: $M_xO_{y-1} + H_2O \rightarrow M_xO_y + H_2$; where M indicate a metal

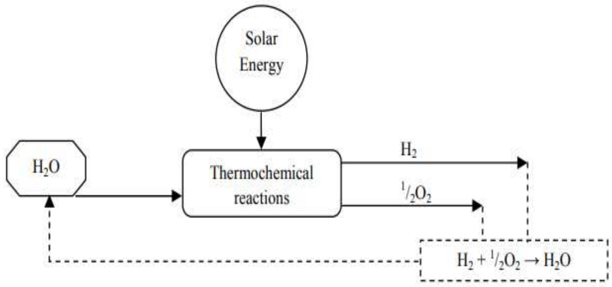

Fig 1. Basic of thermochemical water splitting process

3.2. Photo Electrochemical Process

Photo electrolysis process involves the usage of solar light to produce hydrogen through hydrolysis of water. This method of hydrogen production is also known as photo electrochemical Process. The Photo electrochemical cell consists of two electrodes immersed in an aqueous electrolyte contained within a vessel. The electrodes are pro-active and are illuminated by solar light which can decompose water into hydrogen and oxygen. The electrodes used for this process are semi-conducting materials.

The principal of photo electrochemical process is that when a photon with energy greater than the semiconductor material band gap energy is absorbed at the junction, an electron is released and a hole is formed [2]. In the presence of an electric field, the hole and electron are forced to move in opposite directions if an external load is also connected it creates an electric current [2].

The reaction of photo electrochemical process becomes:

$2hv + H_2O \rightarrow 1/2O_2 + H_2$ where h is the Planck's constant and n is the frequency

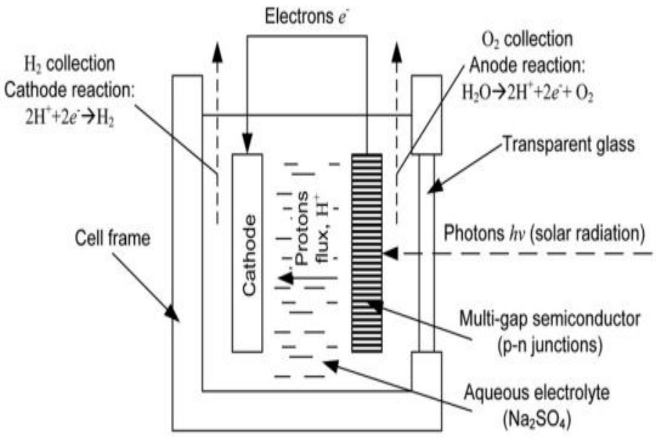

Fig. 2: A simple arrangement of a photoelectrochemical unit

3.3. Electrochemical Process

Water electrolysis is an electrochemical process in which the hydrogen is produced by splitting water using an electrical current passed through two electrodes. The electrolysis of water is not cost-effective unless the electricity comes from a renewable sources like solar energy and wind energy.

The chemical reactions at the anode and the cathode:

At the anode: H_2O + electricity → 2H+ + (1/2) O_2 + $2e^-$

At the cathode: 2H+ +$2e^-$ → H_2

The general electrolysis reaction:

H_2O + electricity→H_2 + (1/2) O_2

Photovoltaic (PV) panels can used to make hydrogen by electrolyzing water with the power produced by the PV cells. A current generated by solar cells can be used to electrolyze water. The electrolysis produces oxygen as a by-product.

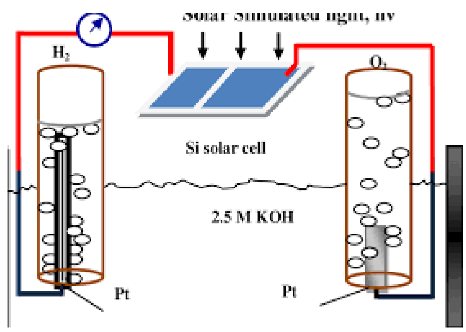

Fig. 3: Photovoltaic based electrolysis

4. HYDROGEN PRODUCTION FROM OFFSHORE WIND FARMS

This hybrid system uses the energy produced from offshore wind farms to produce hydrogen by electrolysis. There are two possible options for the system configuration related to the location of the electrolyzer: it can be placed at offshore, near the wind farm, or onshore, near the existing grid coupling point [3]. An electrolyzer is a device that receives DC current and demineralized water and decomposes the water molecules into hydrogen and oxygen atom through a electrochemical reaction.

Offshore Electrolyzer Scenario:

In this, the electrolyzer used for the production of hydrogen is placed at offshore. The main drawback of offshore wind farms is the transmission losses to bring the electricity to shore considering High voltage Alternating Current. However, in this set up the energy is converted to hydrogen in the offshore electrolyzer. The hydrogen passing through a pipeline has lower losses, under 0.1% [3], along with reduced initial costs for an underwater pipeline compared to underwater electrical cables and the power electronics needed. Hence the system with offshore electrolyzer reduces the transmission losses experienced in an offshore wind farm.

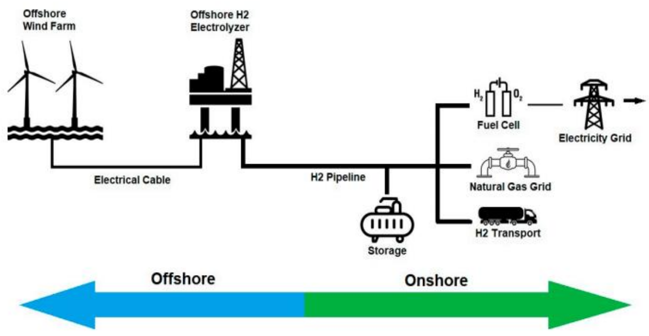

Fig. 4: Offshore electrolyser system

Onshore Electrolyzer Scenario:

The hydrogen is produced from the electrolyser which is available onshore. The main advantage of this system is flexibility to sell electricity to the grid or the electrolyser according to the market price of electricity. There is a need to reduce production when the production of electricity is greater than consumption.

Since in this approach the electrolyzer will be onshore, it is possible to place the electrolyzer and all other sensitive equipment inside a building, where they can be sheltered from the elements. Thus, the maintenance and operation work required for the electrolyzer becomes easier. This provides a better work environment for the person responsible for repair works.

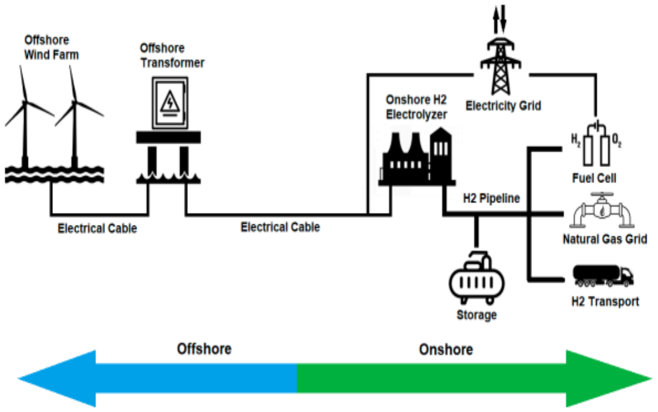

Fig. 5: Onshore electrolyzer system

5. HYDROGEN PRODUCTION FROM BIOMASS

Biomass wood is one of the oldest energy forms used. Biomass is used as a major source of renewable energy in the world to substitute fossil fuel resources. Biomass is going to play crucial role in the future of global energy scenario for heat and power generation and production of chemicals and fuels [4]. In recent years, bio-energy has received particular attention in the energy mix of the world due to fossil fuel depletion and environmental concerns [4].

The hydrogen can be produced from biomass by biological and geothermal processes. The main methods used for Hydrogen production are from biomass feedstock via gasification, steam reforming of bio-oils and pyrolysis as thermochemical conversion processes. Indeed, photo-fermentation, bio photolysis of water using green algae and blue–green algae (cyanobacteria), dark fermentation and hybrid reactor system are the most well-known biological hydrogen production processes [4]. The thermochemical process is adoptable due is its low cost as well as its high efficiency.

6. ADVANTAGES OF HYDROGEN PRODUCTION

- Hydrogen can tackle a number of critical power challenges.
  By the utilization of hydrogen in transport, chemical substances and iron and steel the emissions can be reduced. It therefore enhances air quality and affords energy security. Additionally, the energy system comes to be extra flexible.

- Hydrogen is versatile in phrases of furnish and use.
  It is a free power carrier that can be produced by using a number of renewable power sources.

- Hydrogen can accelerate the contribution of renewable energy sources.

  The variable output energy from renewable energy sources can be stored as hydrogen. This is cost-effective method for storing large quantity of electricity. It also helps in efficient for the transport of renewable energy electricity distantly.

7. LIMITATIONS OF HYDROGEN PRODUCTION

- Today, hydrogen is almost entirely produced from conventional energy sources such as coal and natural gas.
  The production of hydrogen from fossil fuels causes greenhouse gas emission on large scale.

- Producing hydrogen from low-carbon energy is currently costly unless and until renewable energy sources are used.

- Hydrogen must be used much more widely. Currently, the hydrogen usage is restricted to oil refining and for the production of ammonia. The hydrogen needs to be widely used in transport, building and power generation sector to contribute for significant cleaner energy transition.

- The infrastructure required for the hydrogen production is not much developed in many countries. A development is required in terms of the pipelines and shipping solutions to make it more economical and efficient.

8. CONCLUSION

Rapid industrialization has caused an increased energy consumption demand and presently the majority of the energy demand is supplied through fossil fuel resources. Hence, the depletion of conventional energy sources and the impact of fossil fuels on climate change leads the necessity to shift to an alternative source of energy. In this scenario, hydrogen has been introduced as a promising energy carrier for clean development. Solar hydrogen production technology is appealing due its easy availability and loss cost. Also, the environmental impact is significantly reduced because solar is a sustainable source of energy. This paper reviewed various solar hydrogen production methods. Further, it is studied that in wind power plants, hydrogen could be employed as an intermediate energy carrier. The benefits of hydrogen as a carrier in offshore wind farms are relatively high. It was found that the usage of biomass in hydrogen production is helpful to obtain waste-to-well strategy. Besides this the various benefits and drawbacks associated with hydrogen production were also discussed.

REFERENCES

[1] IRENA (2019), "Hydrogen: A renewable energy perspective", International Renewable Energy Agency, Abu Dhabi

[2] Abdul Hadi Abdol Rahim, Alhassan Salami Tijani, Wan Ahmad Najmi Wan Mohamed Suhadiyana Hanapi, and Khairul Imran Sainan, "An Overview of Hydrogen Production from Renewable Energy Source for Remote Area Application" Trans Tech Publications, Switzerland DOI: 10.4028/www.scientific.net/AMM.699.474

[3] Calado, G.; Castro, R. "Hydrogen Production from Offshore Wind Parks: Current Situation and Future Perspectives". Appl. Sci. 2021, 11, 5561. https://doi.org/10.3390/ app11125561

[4] Seyed Ehsan Hosseini n and Mazlan Abdul Wahid, "Hydrogen production from renewable and sustainable energy resources: Promising green energy carrier for clean development", Renewable and Sustainable Energy Reviews 57 (2016) 850–866.