JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

GREEN HYDROGEN FOR SUSTAINABLE FUTURE

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Abstract

Hydrogen produced with renewable energy sources – or "green" hydrogen – has emerged as a key element to achieve net-zero emissions chemical industry and transport. Along with net-zero commitments by growing numbers of governments, green hydrogen has started gaining momentum based on low-cost renewable electricity, ongoing technological improvements and the benefits of greater power-system flexibility. Nonetheless, its potential usage will depend on more than its environmental friendliness. Economic, technical, and safety factors must be assessed. This paper provides a critical assessment of the potential usage of green hydrogen for different purposes with an evaluation of production routes, techno-economic performance, storage, and safety. The paper points out how the concerns of today, including higher costs and technologies under development, can be turned into opportunities for both the public and private sectors.

Key words: Green Hydrogen, production of green hydrogen, Environment friendly technology, Green Energy

Introduction

Decarbonising the planet is one of the goals that countries around the world have set for 2050. To achieve this, decarbonising the production of an element like hydrogen, giving rise to green hydrogen, is one of the keys as this is currently responsible for more than 2 % of total global CO_2 emissions.

This technology is based on **the generation of hydrogen — a universal, light and highly reactive fuel — through a chemical process known as electrolysis [1].** This method uses an electrical current to separate the hydrogen from the oxygen in water. If this electricity is obtained from renewable sources we will, therefore, produce energy without emitting carbon dioxide into the atmosphere.

As the IEA points out, this method of obtaining green hydrogen **would save the 830 million tonnes of CO_2 that are emitted annually when this gas is produced using fossil fuels.** Likewise, replacing all grey hydrogen in the world would require **3,000 TWh/year from new renewables** — equivalent to current demand of Europe. However, there are some questions about the viability of green hydrogen because of its high production cost; reasonable doubts that will disappear as the decarbonisation of the earth progresses and, consequently, the generation of renewable energy becomes cheaper.

Principal Methods

Producing green hydrogen by electrolysis from renewable sources involves breaking down water molecules (H_2O) into oxygen (O_2) and hydrogen (H_2)[3].

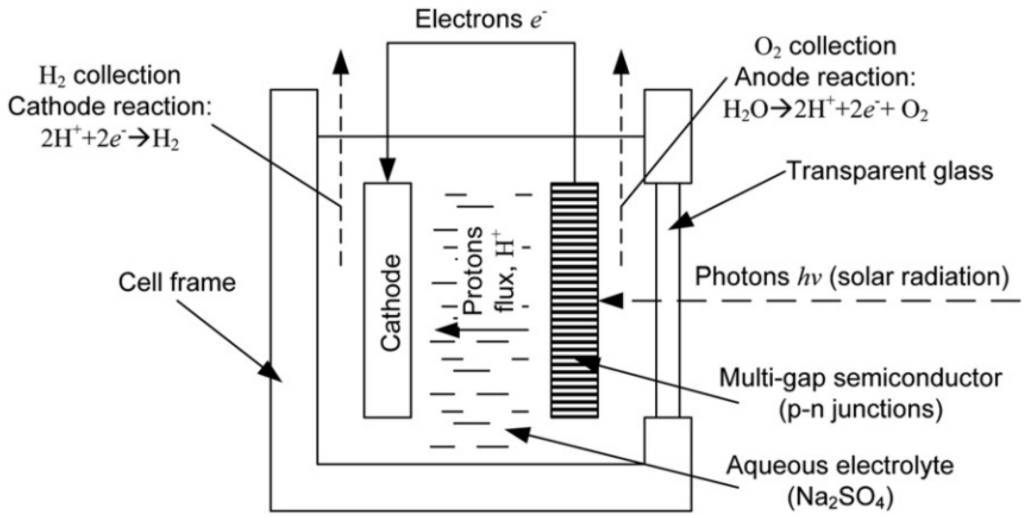

Fig. 2 – Sketch illustrating the operating principle of photo-electrochemical cell.

1. The water used in the electrolysismust contain salts and mineralsto conduct the electricity.
2. Two electrodes are immersed in the water and connected to a power source and a direct current is applied.
3. The dissociation of hydrogen and oxygen occurs when the electrodes attract ions with an opposite charge to them.
4. During the electrolysis, an oxidation-reduction reaction occurs due to the effect of the electricity.

Hydrogen can be produced using a number of different processes [2]. Thermochemical processes use heat and chemical reactions to release hydrogen from organic materials, such as fossil fuels and biomass, or from materials like water. Water (H_2O) can also be split into hydrogen (H_2) and oxygen (O_2) using electrolysis or solar energy. Microorganisms such as bacteria and algae can produce hydrogen through biological processes [3].

Technologies used to generate green hydrogen

Many technologies are developed and many research studies are conducting to split the water and generate green hydrogen in an efficient way and with low cost [4].

Table 1 – Classification of green hydrogen production methods.

Process driving energy	Hydrogen production method		Material resources	Brief description
Electrical energy	Electrolysis		Water	Water decomposition into O_2 and H_2 by passing a direct current which drives electrochemical reactions.
	Plasma arc decomposition		Natural gas	Cleaned natural gas (methane) is passed through an electrically produced plasma arc to generate hydrogen and carbon soot.
Thermal energy	Thermolysis		Water	Steam is brought to temperatures of over 2500 K at which water molecule decomposes thermally.
	Thermocatalysis	H_2S cracking	Hydrogen sulfide	H_2S extracted from seas or derived from other industrial processes is cracked thermo-catalytically
		Biomass conversion	Biomass	Thermo-catalytic biomass conversion to hydrogen
	Thermochemical processes	Water splitting	Water	Chemical reactions (including or not redox reactions) are conducted cyclically with overall result of water molecule splitting.
		Gasification	Biomass	Biomass converted to syngas; H_2 extracted
		Reforming	Biofuels	Liquid biofuels converted to hydrogen
		H_2S splitting	Hydrogen sulfide	Cyclical reactions to split the hydrogen sulfide molecule
Photonic energy	PV-electrolysis		Water	PV panels generate electricity to drive electrolyzer
	Photo-catalysis		Water	Complex homogeneous catalysts or molecular devices with photo-initiated electrons collection are used to generate hydrogen from water
	Photo-electro-chemical method		Water	A hybrid cell is used to generate photovoltaic electricity which drives the water electrolysis process
	Bio-photolysis		Water	Biological systems based on cyanobacteria are used to generate hydrogen in a controlled manner
Biochemical energy	Dark fermentation		Biomass	Anaerobic fermentation in the absence of light
	Enzymatic		Water	Uses polysaccharides to generate the required energy
Electrical + thermal	High temperature electrolysis		Water	Uses a thermal source and electrical power to split water in solid oxide electrolyte cells
	Hybrid thermochemical cycles		Water	Use thermal energy and electricity to drive chemical reactions cyclically with the overall result of water splitting
	Thermo-catalytic fossil fuels cracking		Fossil fuels	A thermo-catalytic process is used to crack fossil hydrocarbons to H_2 and CO_2, whereas CO_2 is separated/sequestrated for the process to become green
	Coal gasification		Water	Coal is converted to syngas, then H_2 extracted and CO_2 separated/sequestrated (electric power spent)
	Fossil fuels reforming		Fossil fuels	Fossil hydrocarbons are converted to H_2 with CO_2 capture and sequestration (electric power spent)
Electrical + photonic	Photo-electrolysis		Water	Photo-electrodes + external source of electricity
Biochemical + thermal	Thermophilic digestion		Biomass	Uses biomass digestion assisted by thermal energy for heating at low grade temperature
Photonic + biochemical	Bio-photolysis		Biomass, water	Uses bacteria and microbes to photo-generate hydrogen
	Photo-fermentation		Biomass	The fermentation process in facilitated by light exposure
	Artificial photosynthesis		Biomass, water	Chemically engineered molecules and associated systems to mimic photosynthesis and generate H_2.

2.1. Electrolytic cell

Direct current/electricity is passed through two electrodes immersed in water to split the water molecules and generate hydrogen at the cathode and oxygen at the anode. Currently, many kinds of electrolysis could be used in this method. Some of these method use a liquid electrolyte like the aqueous solution of potassium hydroxide (KOH) due to its high conductivity and are known as the alkaline electrolyser (unipolar and bipolar). Another method uses an electrolyte as a solid ion conducting membrane and is known as proton exchange membrane electrolyser (PEM). Compared to alkaline electrolyser, PEM could supply lower gas exchange, higher proton conductivity, lower membrane thickness and it can perform under high pressure. Sea water can be used as an aqueous electrolyte in the electrolysis process since it is more abundant than pure water. It does not require a pre-treatment and purification, resulting in cutting their associated cost. In sea water electrolysis, hydrogen evolution reaction is composed at the cathode and chlorine evolution is composed at the anode. The drawbacks of the use of sea water are the corrosion of the equipment and the generation of chlorine as by product.

2.2. Photo electrode device

Photo electrode device is viewed as a promising option for green hydrogen generation to overcome the thermodynamic barrier in the water electrolysis. A semiconductor electrode is used to separate hydrogen and oxygen from water by using the photo-absorption method that creates electron-hole pairs at the semiconductor areas. A separation of the pairs into electrons and holes occurred thanks to the surface band bending on n-types semiconductor. The holes and electrons minimize and oxidize water to generate hydrogen and oxygen, successfully. Nanotechnology is used in the green hydrogen generation by creating a novel sunlight-photosensitive-nanostructured electrode. This electrode subjects to photo catalyst to be able to split water molecules intro hydrogen and oxygen under the sun's light. The benefit of nanostructure derives from its ability to boost the operational surface area of the electrode, thus augment the performance of electrode for green hydrogen generation.

2.3. Solar cells

Water splitting is performed by the photo voltage of connected solar cells. Many joined crystalline cells (like Si and CIGS) are probable due to the solar to hydrogen performance and solar-operated durability for hydrogen generation. The benefit of CIGS is the capability to modulate the ban gap energy to efficaciously soak up the solar spectrum. Perovskite solar cells can be used also to drive water splitting. Two perovskite cells connected in series, compared to at least three to four Si or CIGS cells, can achieve open circuit voltages at 0.9 V, which is adequate for an effective water splitting. According to, the cost of hydrogen generated by the PV-electrolysis is more than $5/kg and the efficiency is less than 5%. conducted a study to improve the performance and the hydrogen generation of a hybrid system of electrolysis and PV to generate hydrogen. Results showed that the performance and hydrogen generation could be improved by thermal integration. Besides, Concentrator photovoltaic (CPV) can be used to run an electrolysis. The solar to hydrogen efficiency (STH) of CPV-electrolyser reaches the highest of 28% using alkaline system, to now.

<u>Advantages and Disadvantages of Green Hydrogen</u>

This energy source has pros and cons that we must be aware of [5]. Let's go over some of its most important good points:

- **100 % sustainable:** green hydrogen does not emit polluting gases either during combustion or during production.
- **Storable:** hydrogen is easy to store, which allows it to be used subsequently for other purposes and at times other than immediately after its production.
- **Versatile:** green hydrogen can be transformed into electricity or synthetic gas and used for commercial, industrial or mobility purposes.

However, green hydrogen also has **negative aspects [6]** that should be borne in mind:

- **High cost:** energy from renewable sources, which are key to generating green hydrogen through electrolysis, is more expensive to generate, which in turn makes hydrogen more expensive to obtain.
- **High energy consumption:** the production of hydrogen in general and green hydrogen in particular requires more energy than other fuels.
- **Safety issues:** hydrogen is a highly volatile and flammable element and extensive safety measures are therefore required to prevent leakage and explosions.

Applications

1. Replacing existing hydrogen feedstock

Perhaps the most obvious use for green hydrogen is to simply replace the large amounts of the gas that are already produced using carbon-intensive methods to satisfy the needs of industry [7]. Based on International Energy Agency figures, 38.2 million metric tons (MT) of hydrogen were used for oil refining in 2018; another 31.5 MT went toward ammonia production.

Steelmaking is another potential target for green hydrogen, with several organizations developing direct reduced iron processes that use the gas to remove oxygen from ore, according to NREL.

In 2015, the total U.S. hydrogen feedstock market amounted to 10 MT, and McKinsey estimates this could rise to between 13 MT and 14 MT by 2030.

2. Heating

Decarbonizing residential and commercial heating systems is a major challenge in countries that currently rely on natural gas to do the job [9]. One immediate — albeit partial — answer to the problem is to mix green hydrogen into natural gas to reduce the latter's carbon content.

But this is only likely to be worthwhile in places where natural-gas prices are relatively high, such as in Europe. And there are limits to how far you can go.

"Blending up to 20 percent hydrogen (on a volume basis) is likely to be feasible for natural-gas applications, although not all natural-gas pipeline systems are constructed of materials that can withstand that concentration," said NREL researchers in an article published in August.

3. Energy storage

A much-vaunted use of green hydrogen is to use it for electricity production via fuel cells [8]. But there are significant challenges to overcome.

If the hydrogen is produced from renewable energy via electrolysis, the AC-to-AC round-trip efficiency falls to around 35 percent, far below the 95 percent efficiency that can be achieved with batteries.

Nevertheless, an NREL study published earlier this year found it would make financial sense to use green hydrogen for energy storage applications with a duration of 13 hours or more — and that's using today's technology.

4. Alternative fuels

Although it's used widely for industrial purposes, scaling up hydrogen production for a wider range of applications poses challenges relating to distribution and storage.

One way to get around these is to convert the highly volatile and flammable gas into a slightly more malleable fuel such as ammonia or methane. Since energy would be lost in this conversion, however, it would likely only be worth doing where the value of the resulting product is relatively high.

Hence, says NREL, "Market opportunities are likely to be driven either by a desire to use carbon dioxide or by the ability to tailor specific products that may be difficult to produce directly from natural gas."

5. Fuel-cell vehicles

Powering fuel-cell vehicles is one of the most often-cited applications for green hydrogen. But it remains to be seen whether fuel-cell vehicles can gain traction as automotive markets flip from internal combustion engines to increasingly cost-competitive battery-powered cars.

“In the next 10 years, there’s probably more attractive uses for green hydrogen than putting it into cars,” said Colin McKerracher, head of advanced transport at the analyst firm Bloomberg New Energy Finance.

The exception might be in specialist transportation areas such as heavy-duty trucking or forklifts. McKinsey estimates there is an immediate market for 25,000 forklift trucks and other material-handling fuel-cell vehicles in the U.S., compared to just 7,600 hydrogen-powered cars on the road.

Conclusion

This paper identifies and categorizes the principal methods to produce green hydrogen. Material resources from which hydrogen can be extracted are many, but those of prime importance are water, sea water, hydrogen sulphide, biomass and fossil hydrocarbons. When fossil hydrocarbons or coal are used in the process, precautions must be taken to extract and sequestrate the resulting carbon dioxide, if it is the case, such that the production process is environmentally benign. Electrical, thermal, biochemical and photonic energy or combinations of these are identified as the key commodities to drive hydrogen production process. These basic forms of energy can have been obtained from green energy sources like renewables, nuclear or waste energy e through various conversion paths. Of course, each production method has advantages and disadvantages. Selection of these requires various criteria, namely, environmental impact, efficiency, cost effectiveness, resources and their use, commercial availability and viability, system integration options, to be considered.

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