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Biohydrogen - An Alternate Promising Future Energy Source

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ABSTRACT: In the global market, the demand for energy is increasing along with the increasing population. To meet the demands, the source of energy plays an important role in the development of a nation's economic growth and development. But in the current situation due to depletion of fossil fuel sources, renewable energy acts as an alternate energy source with their own advantages and limitations. Even energy production technologies from various sources have to be cost-effective, sustainable, and efficient. Many studies emphasized hydrogen as the better feasible and alternative energy source produced even from biomass of food, agricultural wastes, fossil fuels, and even wastewater with a wide variety of applications. Hence this review mainly focused on hydrogen production by biological methods. Along with its proper storage and handling which plays an important role in acting as an efficient energy source for hydrogen fuel cells. Among biological methods, processes like Photobiological, Fermentative, and Anaerobic digestion were used for the generation of Hydrogen obtained by recycling food waste, and agricultural wastes. Hence the researchers are aiming at various strategies to increase the yield of Biohydrogen, to reach the demands of energy across the globe.

KEYWORDS: Anaerobic digestion, Biomass, Biohydrogen, Fermentation, Renewable energy.

INTRODUCTION

Energy is a very important source for mankind to sustain. The degradation or extension of fossil fuels is driving researchers to an alternative source of energy. The most common renewable sources of energy are solar, wind, hydro, tidal, geothermal, and bio energies. These future renewable alternative sources of energy are already in the stage of implementation, but these sources need to be sustainable, efficient, and cost-effective [1]. These renewable energies individually have their own merits and limitations which are summarized together in Table I. There are many factors that drives these renewable energy sources.

Table I: Merits and limitations of alternatives sources of Energy

Merits	Limitations
Renewable energy won't run out	Renewable energy has high upfront costs
Renewable energy has lower maintenance requirements	Renewable energy is intermittent
Renewables save money	Renewables have storage capabilities
Renewable energy has numerous environmental benefits	Renewable energy sources have geographic limitations
Renewables lower reliance on foreign energy sources	Renewables aren't always 100% carbon-free
Renewable energy leads to cleaner water and air	
Renewable energy creates jobs	
Renewable energy can cut down on waste	

Of these different sources of alternative energies Bioenergy sources are one prominent alternative. Helena L. Chum et al in their review on Biomass and renewable fuels discussed about the sources, feasibilities and policies required to be adopted in order to make this alternative sources and Biomass for commercial utilization. Also discussed about multiple energy options from biomass and the long term hydrogen production technologies with commercial utilization to adapt to today's fuel and vehicle infrastructures [1]. Jarunee Wonglimpiyarat in their case study on Thai government agencies to understand the ways the agencies can facilitate the technological innovations in the field of alternative energies sources for the increasing high oil prices, economic security and sustainability. The analysis is done by considering pre-foresight exercise to evaluate the feasibility and potential of bio-based energy, also to workout on the development policies required for energy system development [2].

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Bioenergy is embedded in different ways in the world of biomass systems for food, fodder and fiber production, this energy exists with different technologies in different forms for different applications. Helena Chum et al in their work on Bioenergy discussed about the potentials, logistics, market and industry development, environmental and social impacts, cost trends and potential deployment in global and regional conditions. Work also focused on commercial and deploying bioenergy routes from biomass also there is a detailed analysis on influence of climate change uncertainties on bioenergy [3].

M. Gomes et al in their work on biofuels production and environmental impact on global and local found that there is a huge difference in the production and consumption of the fossil and biofuels. Also its stated that the energy matrix indicates the 90% usage of fossil fuels and to replace the trend with biofuels takes long time [4].

Of these different sources and methods available researchers are working on the hydrogen as this is a better feasible and alternative source for the transportation and infrastructure sector. Hydrogen is ideally an energy carrier which is non pollutant. Although hydrogen is the most abundant element in the universe, it does not naturally exist in its elemental form on Earth. Pure hydrogen must be produced from other hydrogen-containing compounds such as fossil fuels, biomass, or water. Each method of production requires a source of energy, i.e., thermal (heat), electrolytic (electricity), or photolytic (light) energy. Hydrogen is either consumed on site or distributed to end users via pipelines, trucks, or other means. Hydrogen can be stored as a liquid, gas, or chemical compound and is converted into usable energy through fuel cells or by combustion in turbines and engines. There are many key challenges to be addressed in order to use hydrogen as a successful commercial alternative fuel. There are many global industries that are successfully producing and using hydrogen as fuel along with technological advancement in production [5].

Hydrogen does not exist alone in nature. Natural gas contains hydrogen (about 95% of natural gas is methane, CH_4), as does biomass (cellulose) and hydrocarbons, like coal. An equally diverse array of primary energy sources, such as wind, solar, geothermal, nuclear, and hydropower, can be used to extract hydrogen from water. It's this diversity of options that enables hydrogen production almost anywhere in the world. Meiling Yue et al in their review on hydrogen energy systems discussed the importance and role of hydrogen as fuel in decarbonization in different sectors like power generation, transportation, industries, etc. Also discussed about the key technologies that facilitate hydrogen integration into the energy sector in terms of production, storage, and utilization. Further stated that the policies have to be changed in order to enhance the technologies to produce hydrogen as fuel with cost-effectiveness [6].

Though there are some methods with the help of which we can produce hydrogen. All hydrogen production processes are based on the separation of hydrogen from hydrogen-containing feedstock discussed in Table 2. The feedstock dictates the selection of the separation method. Today, two primary methods are used to separate hydrogen: thermal and chemical. A third method, biological, is in the exploratory research and development phase.

Table II: Methods of production of Hydrogen [7]

Primary Method	Process	Feedstock	Energy
Thermal	Steam Reforming	Natural Gas	High temperature steam
	Thermo chemical splitting	Water	High temperature heat from nuclear reactor
	Gasification	Coal, Biomass	Steam and oxygen at high temperature and pressure
	Pyrolysis	Biomass	Moderately high temp. Steam
Electrochemical	Electrolysis	Water	Electricity from wind, Solar, Hydro and Nuclear
	Electrolysis	Water	Electricity from coal or natural gas
	Photochemical	Water	Direct sunlight
Biological	Photobiological	Water and algae strains	Direct sunlight
	Anaerobic Digestion	Biomass	High temp. heat
	Fermentative Microorganisms	Bio Mass	High temp. heat

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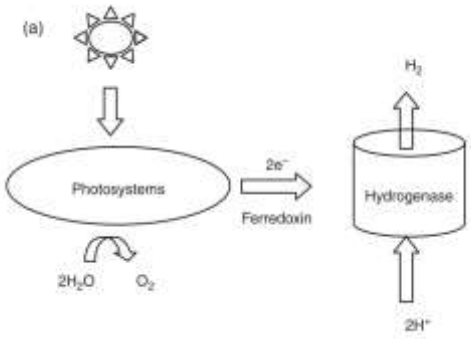
Fossil fuel currently is the main source of hydrogen production. Hydrogen can be generated from natural gas with approximately 80% efficiency or from other hydrocarbons to a varying degree of efficiency. Specifically, bulk hydrogen is usually produced by the steam reforming of methane or natural gas. At high temperatures (700–1100 °C), steam (H2O) reacts with methane (CH4) to



yield syngas.

$CH_2 + H_2O \rightarrow CO + 3H_2$ `(1)

Gasification

In a second stage, further hydrogen is generated through the lower-temperature water gas shift reaction, performed at about 130 °C:

$CO + H_2O \rightarrow CO + H_2$ (2)

Partial oxidation

The partial oxidation reaction occurs when a sub stoichiometric fuel-air mixture is partially combusted in a reformer, creating a hydrogen-rich syngas.

General reaction equation:

$C_nH_m + \frac{n}{2}O_2 \rightarrow n\,CO + \frac{m}{2}H_2$ (3)

Possible reaction equation:

$C_{12}H_{24} + 6\,O_2 \rightarrow 12\,CO + 12H_2$ (4)

Coal

Coal can be converted into syngas and methane, also known as town gas, via coal gasification. Syngas consists of hydrogen and carbon monoxide.

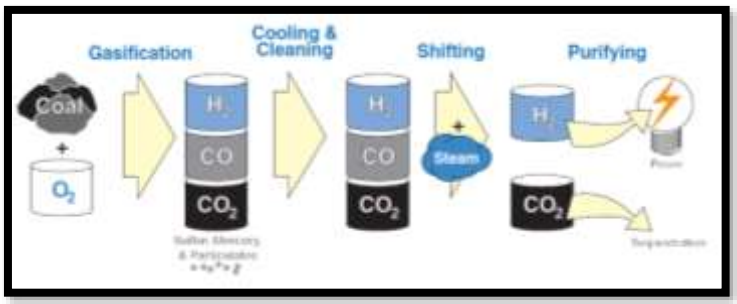


Figure 1: The Gasification Process

1. From water

The hydrogen can be extracted from water by electrolysis and thermolysis.

Electrolysis

Hydrogen is produced on an industrial scale by the electrolysis of water. While this can be done with a few volts in a simple apparatus like a Hofmann voltmeter.

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Thermolysis

Water spontaneously dissociates at around 2500 C, but this thermolysis occurs at temperatures too high. Catalysts are required to reduce the dissociation temperature.

2. From Biological sources

Biophotolysis of water is used for the production of molecular hydrogen from algae and cyanobacteria it can be carried out either direct or indirect means (with or without light irradiated) during hydrogen evolution as shown in Figure 2.

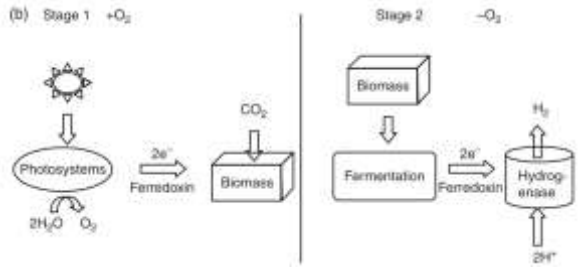

Figure 2: (a) Direct Method (b) Indirect biophotolysis of water [8]

The main drawback of the direct method is the process is limited because of the strong inhibition of hydrogenase by oxygen produced other than low light conversion efficiencies. In case of indirect method environmental conditions such as temperature, salinity, nutrient availability, gas at the atmosphere etc. plays major role in the production of hydrogen [8].

Biological water gas shift reactions is another new method in production of hydrogen where certain photo-heterotrophic bacteria like Rhodospirillum rubrum and Rubrivivax gelantinosus perform reactions at ambient temperature by using CO as source oxidizing it to CO2 and reducing H+ to H2 as shown in reaction below [8];

$$CO + H_2O \rightleftarrows CO_2 + H_2$$

Microbial Electrolysis Cell is another method of hydrogen production where the Microbial Fuel Cell (MFC) converts biodegradable material to hydrogen. MFC reaction involves migration of protons released from organic substrate at anode through the external load to cathode to combine with oxygen to form water. Small external voltage is applied to the cell where the anodic reactions are combined to form hydrogen at cathode [8].

The photoheterotrophic or photo-fermentative process of hydrogen production is a microbial process in which organic substrates are oxidized under anaerobic conditions in the presence of light [8].

Dark fermentation is an alternative method for biological hydrogen production from biomass. It is a process that is carried out in the dark, under anaerobic conditions, and it is directly related to the acidogenic stage of the anaerobic digestion process [8].

Scenario and influencing parameters for the production of Biohydrogen

Hydrogen generation by recycling food waste, and agriculture industries by using the anaerobic bacteria by dark fermentation [7]. Hang-Sik Shin et al in their work on hydrogen production from food waste in anaerobic mesophilic and thermophilic acidogenesis found that acidification of the organic waste requires 5days as Hydraulic Retention Time (HRT) showed effective hydrogen production. Also, it is found that higher hydrogen production in thermophilic acidogenesis than mesophilic which is caused by free of methane and negligible propionate. Even with the increase of volatile solids the quality and quantity of hydrogen production and with PCR-DGGE analysis it was found that there is more chance of hydrogen production from carbohydrate rich food waste with sufficient HRT [9]. Ze-Kun Lee et al in their work on hydrogen production by seeding sludge reaction thermophilic method on kitchen vegetable waste found 1 L-H2 L-1day-1 with hydrolysis efficiency of 32%. The dominant OTU was closely affiliated to Thermoanaerobacterium thermosaccharolyticum, which is considered as the predominant hydrogen-producing bacteria. The OTUs closely related to Moorella thermoacetica and Clostridiaceae bacterium FH052 were considered as acetogenic bacterium and hydrogen-producing bacteria in the I-CSTR system [10].

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Moon H. Hwang et al in their work on hydrogen production from ethanol fermentation found that pH plays major role in determining the type of anaerobic fermentation pathway in anaerobic bio-hydrogen processes. The method used to determine is the operation of semi-continuously operated reactor for the production of hydrogen and a batch test is conducted to for investigation of pH effect in determining the path way of bio-hydrogen processes. It is found that below pH-4 the activity of all the microorganisms was inhabited which is regarded as the operational limit for the hydrogen production process [11].

The major factors to be considered in biohydrogen production is Hydraulic Retention Time (HRT), pH, volatile solid organic compounds, presence of carbohydrates etc. Other challenges associated with hydrogen is cost and handling. There are many ways for enhancing the performance of anaerobic digestion process such as through simulation, co-digestion, addition of surfactants, pre-treatment and optimal digester design [12]. M. Kim et al in their work on fermentative biohydrogen production from solid waste found that the hydrogen production is not only depends on the composition of organic waste but also depends on operational conditions like pH range from 5 to 6, thermophilic conditions like HRT, operational temperature, process stage and reactor type etc [13]. The yield and synthesis of H2 has to be increased, this depends on enhanced technologies and procedures. There are certain factors that are needed to be improvised like bioprocess integration, optimization of reactors design for the production of hydrogen, rapid removal and purification techniques [14].

Storage of Hydrogen

Storage of hydrogen is biggest issue because it is highly instable not only this even if the system is made for on board hydrogen storage for applications like automobile it is tough to handle because of lowest energy density [15]. Another important issue with hydrogen is its colorless and odorless which makes it difficult from leakage. Another important factor that influences the storage is it occupies very large volume for this the present alternative is liquification of hydrogen means it is handled at cryogenic temperatures. The storage system requires a high storage pressure to avoid inconveniences, the use of materials that attract a large number of hydrogen molecules, or a shallow storage temperature [16].

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