Review on Waste- to- Hydrogen (WtH) Approach and the SDGs

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Abstract

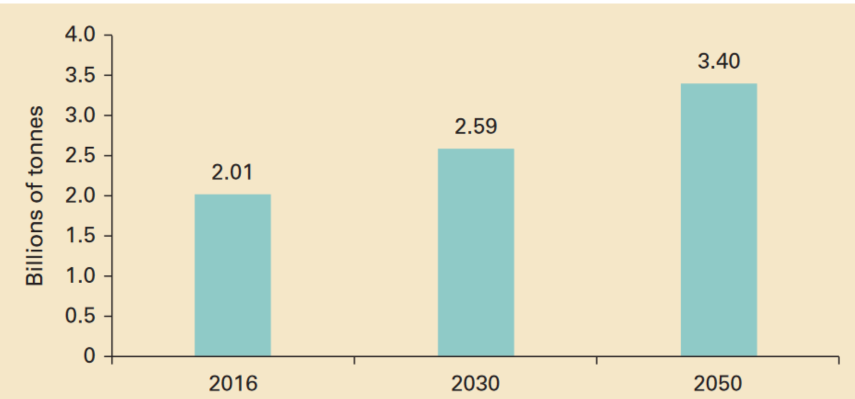
Different waste to hydrogen technologies can provide more efficient waste management solutions other than landfilling and incineration, which are found to be more sustainable. Converting waste into hydrogen is seen as one of the promising techniques towards renewable energy generation. Therefore, waste to hydrogen (WtH) can be considered one of the zero-carbon energy methods that can be produced from biomass, plastic municipal waste, agriculture waste, and industrial wastes using different techniques. Further, biowaste is considered the only renewable energy source of carbon and hydrogen which can be converted into fuels to be used in different applications, such as transportation. This review paper includes different methods of producing clean hydrogen, its applications, and its challenges. Furthermore, the contribution of W2H to the accomplishment of the SDGs is discussed in brief.

Keywords: Biomass, Gasification, Pyrolysis, WtH, Clean hydrogen, SDGs.

1. Introduction

According to the World Bank reports, the municipal waste generation is over 2 billion tons annually worldwide with an average of 0.74 kilogram/person, and in 2050 these values are expected to reach 3.40 billion tons/year, as shown in Fig.1. Also, with the growing population rate of 1.18% annually, global waste generation is expected to reach 6 million tons daily by 2025 [6].

Fig. 1 Projected Waste Generation Globally



Source: (Kaza et al., 2018)

The conventional methods for waste management like landfilling and incineration emit vast amounts of CH_4 that has a global warming potential of 21 times CO_2, over 100 year period, which has adverse impacts on the environment [7]. Hence, it is crucial to implement sustainable waste management strategies to overcome the pressure of increasing waste disposal and its negative impacts on the environment.

Different waste treatment methods can create energy in the form of electricity and other fuels. Hydrogen production is considered one of the waste treatment applications, as hydrogen is viewed as an energy carrier and alternative fuel with a high calorific value for electricity generation [2]. It is regarded as a particular form of energy from waste (EfW) as it contains the highest energy content per unit of weight among the other most used fuels. Hydrogen has the potential to assist in the process of decarbonization of the energy sector by replacing fossil fuels with clean hydrogen produced from renewable sources [14]. According to the EIA website, hydrogen fuel cells were firstly used by NASA in order to produce the energy required for operating the electrical system on the spacecraft. The hydrogen fuel cells generate electricity by combining the atoms of oxygen and hydrogen, where the oxygen reacts with hydrogen in an electrochemical cell [13].

There are different methods to produce clean hydrogen from waste, such as thermochemical processes (gasification and pyrolysis), and biological procedures (fermentation and photolysis). The conventional hydrogen production technologies are considered highly energy-intensive, and they create high CO_2 emissions. The widely used conventional methods are catalytic decomposition, partial oxidization, and steam reforming of natural gas, heavy hydrocarbons, and crude oil. Such technologies can be replaced by alternative processes, including thermochemical conversion, biochemical methods, and water via electrolysis which produces low carbon hydrogen [7].

Some factors that affect the improvements of hydrogen output are related to the advanced energy processing of feedstock, such as torrefaction. However, there are some challenges regarding the process of WtH, including the high cost of the operation and production, the lack of supporting policies and management strategies, heterogeneous feedstock, and the low efficient procedures [7]. Besides, one of the limiting factors for depending on hydrogen in the industry is high market uncertainty and supply chain risks [1].

In the following, the concepts of the thermochemical and biological methods of clean hydrogen production will be explained.

2. Analysis and Discussion

In order to implement efficient WtH technologies, there are some components for the suitable feedstock, as it shall include MSW, sewage sludge, plastics, SRF, and RDF. Thermochemical conversion (gasification and pyrolysis) is often used for recycling food, agriculture waste, and plastics because they are rich in carbon. It is used to produce hydrogen from waste which contributes towards achieving energy security, reducing waste disposal, and decreasing the dependency on fossil fuels [7]. In this section, different research papers are reviewed to better understand the possible techniques used in producing hydrogen from waste.

2.1 Technologies

2.1.1 Thermochemical methods

Gasification of waste is considered an effective thermochemical conversion technique, and it is the most studied method among the others. The research found that hydrogen concentration from the gasification of mixed waste feedstock is around 82%. The gasification process is based on converting solid matters into gases within a reactor in the presence of oxygen in temperatures of 500 to 1200 C and 0.1Mpa pressure. It is essential before gasification that the feedstock is treated to reduce the moisture content to aid the process and improve the quality of the produced syngas. Gasification is challenging because biowaste contains 75%-85% of volatile matters that are released, leading to the formation of tar, which is hard to break down and condenses, causing difficulties in the process. In the gasification process, the oxidation stage should be controlled to ensure that all the volatile matter is exposed to the oxidizing agent to produce high-quality syngas and char. Also, the efficiency of the gasification process may be affected due to losses of hydrogen and carbon in the feedstock. Thus, pyrolysis is crucial in the gasification process to ensure high-quality syngas production [11].

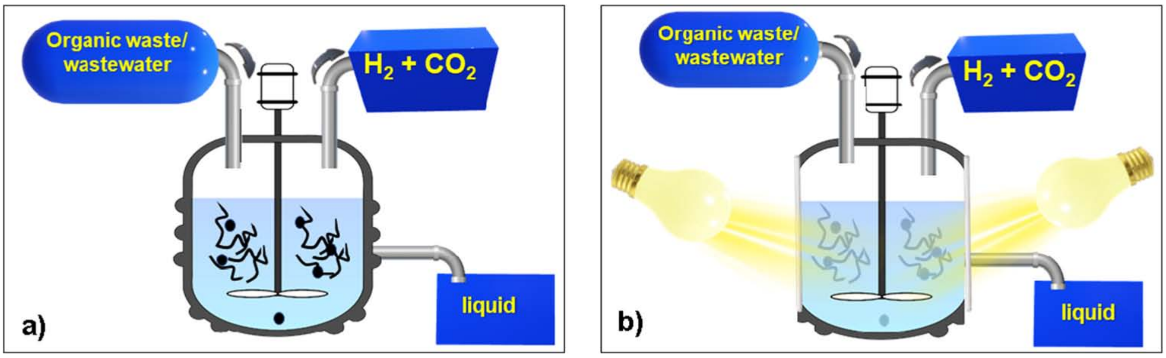
Some simulation software programs are used to design and simulate gasification units, such as Aspen Plus® which contains a library model for the bed reactor. Such simulations are used to predict the composition of synthesis gas produced, the hydrogen yield for a specific feedstock, define the suitable gasifying agent, and the required operating conditions of the gasifier [12].

2.1.2 Biological methods

Moving to the biological methods of hydrogen production, some research papers claim that they have more advantages over the thermochemical techniques as they don't need high energy requirements. The biological procedures include two major methods: bio-fermentation (dark fermentation and photo-fermentation) of organic matters using bacteria, and bio-photolysis (direct and indirect) of water using algae. Such processes depend on light and use photobioreactors to produce clean hydrogen [8].

Regarding fermentation, it is the process of utilizing microorganisms to get H2 and other by-products from biowaste. Dark fermentation is done in dark anaerobic circumstances, while the photo-fermentation is carried out in the presence of light (natural or artificial) and photosynthetic bacteria, and studies found that using both of the fermentation methods can lead to improving the yield of the produced H2, shown in Fig.2. The main drawback of fermentation is that the actual production rates of hydrogen are lower than the theoretical rates [9].

Fig. 2 a) Dark Fermentation and b) Photo-fermentation of hydrogen production out of organic waste.



Source: (Osman et al., 2020)

Dark fermentation is where anaerobic microorganisms work on substrates that are rich in carbohydrates in dark conditions, and it can react in various feedstock such as food and paper waste and sludge. It doesn't demand high energy and it has the ability to merge with other procedures. This type of fermentation breaks down biomass into alcohols, organic acids, hydrogen, and CO2. Glycolysis is the most preferred substrate for this process, and it can be generated from agricultural waste which is less costly. The hydrogen yield in the process is affected by different factors, the concentration of the substrate should not be high to avoid lowering the yield, also the types of the used microorganisms and the conditions of the reactions can affect the yield.

While photo-fermentation is the process from which hydrogen and CO2 are produced by photosynthetic bacteria within anaerobic conditions at 30-35°C. The bacteria in this process require nitrogen-deficient circumstances with organic acids and sunlight in order to convert organic acids into hydrogen. The hydrogen yield here can be affected if the efficiency of the light conversion is low. Both dark fermentation and photo fermentation processes can be combined together into a hybrid system that will decrease the light requirements and increase the yield. Some research papers found that this hybrid system resulted in a theoretical H2 yield of 12 mol/mole glucose, and adding biochar will increase the yield and the production rate, as well as reduce the fermentation lag time by 4.4 ± 0.5 h [7].

The second biological method is bio-photolysis which needs light and water as a reactant; glucose and biowaste are involved in this process, as well. For the direct bio-photolysis, the light is absorbed by a photosystem where the electrons are transferred to ferredoxin (F), which will reduce the water and the ferredoxin. Then the ferredoxin transports the electrons to the biohydrogen enzyme (called hydrogenase) that converts a proton into biohydrogen. One of the main drawbacks of direct bio-photolysis is that it produces oxygen that hinders the activity of the hydrogenase. Regarding the indirect bio-photolysis, it operates in two steps. In the first step large amount of biomass is produced from a photosynthetic system in order to maximize the amount of carbohydrates. This carbohydrate is the source of carbon used in the second step in which carbon plays the same role as water in the direct bio-photolysis, and this step is also similar to fermentation. The indirect process is more efficient than the direct one because the oxygen doesn't hinder hydrogen production [8].

2.2 WtH and SDGs

Waste to Hydrogen is one of the Waste to Energy solutions, and it is considered a circular approach to waste management that will contribute to achieving decarbonization in Europe when used in energy-intensive industries and transportation. Through this method, the energy produced can generate low carbon-hydrogen and can be used as an alternative fuel, sourced from renewables [5].

Different initiatives called for hydrogen to be included in the European energy mix, especially by Germany and Portugal. In 2020, the European Hydrogen Strategy was adopted by the European Commission, then the European Clean Hydrogen Alliance was created in the same year, followed by Clean Hydrogen Partnership in February 2021. The partnership was issued to continue the work of the current funding instruments for hydrogen-related projects, such as the Fuel Cells and the Hydrogen Joint Undertaking (FCH JU) which were created in 2008 and supported about 285 projects in the public and private sectors. According to the European Hydrogen Strategy, the European energy mix is expected to have 14% of it to be hydrogen, by 2050 [4].

In 2020, the European Commission initiated the Hydrogen Strategy that aims to decarbonize hydrogen production and use it for energy applications instead of burning fossil fuels. For instance, Germany is one of the first EU countries to sign bilateral agreements for importing hydrogen produced from solar power in Australia, which contributes directly to SDG 17: Partnerships for the Goals. It is expected that by 2050, 24% of the global energy demand will be achieved through clean hydrogen, with annual sales of 630 billion EUR. All Member States of the European Union have already incorporated clean hydrogen schemes into their national energy strategies. The EU Hydrogen strategy identifies the vision of the methodology that the EU can follow in order to make clean hydrogen a feasible solution to achieve decarbonization in various sectors, also it addresses the challenges and determines the actions that the EU can take as coming steps. It aims to establish 40 GW of renewable hydrogen electrolysis by 2023 and more than 6GW in 2024 [1].

Furthermore, the WtH process plays an important role in developing a successful waste management strategy, providing renewable energy sources, and reducing the carbon footprint. Hence, seven sustainable development goals will be met, which are SDG 7, SDG 8, SDG 9, SDG11, SDG 13, SDG 15, and SDG 17. By focusing on the achievement of SDG 7: Affordable and Clean Energy, WtH provides an optimum solution to improve energy productivity by providing cheap and clean sources of energy to all countries around the globe. Consequently, the remaining mentioned SDGs can be achieved.

2.3 Initiatives

Different countries around the world realized the importance of WtH and started taking serious action for adopting WtH strategies and technologies. One of these countries is

Germany. It started a project for the WtH plant with an investment of 70 million EUR in Permnitz since 23 April 2021. This project is being implemented by the German Richter Group and a Swedish technology company called Plagazi. By 2023, the project intends to transfer 44 thousand tons of composites and non-recyclable plastic waste into 7.5 thousand tons of clean hydrogen and 100 thousand tons of liquified CO2, using plasma gasification technology [4].

Another example is India which is one of the countries considering green hydrogen production to substitute fossil fuels and reach the planned target of 60%, equivalent to 450 GW in 2030. A group of researchers from different entities in India is working on developing WtH technology based on agriculture waste, and the director of this team claims that this technology has an efficiency of 25% [10].

3. Conclusion and recommendation

After reviewing various available research studies, it is found that WtH is a promising movement that contributes to achieving successful waste management strategies, as well as finding sustainable solutions to produce energy that can be used in different applications, such as the transportation sector, energy-intensive industries, and electricity generation. However, there are some drawbacks of the used hydrogen production technologies, such as the feedstock quality and the moisture content, which affect the hydrogen yield. Therefore, many countries started paying attention to the WtH concept as they started planning and implementing hydrogen power plants using innovative technologies to maximize the efficiency of the hydrogen production methods and overcome the potential challenges. Moreover, such countries can effectively meet the sustainable development goals and their global responsibility commitments.

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