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Current development and technologies of hydrogen production

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Summary

Hydrogen plays an important role in today's energy transformation, which has been considered as the most impressive energy source to replace traditional fossil fuel. However, decarbonization in the process of hydrogen production has not been realized yet. This paper compares three principal hydrogen production technologies and analyses the current development status. It is found that hydrogen produced from renewable energy should be the most promising solution for future hydrogen applications in terms of sustainability and environmental friendliness.

Keywords: hydrogen production, electrolysis, methane steam reforming, coal gasification.

1 Introduction

Hydrogen is the most abundant gas in the universe and has the maximum energy content per unit of weight compared to any other known fuel [1,2]. The average efficiency of hydrogen is 1.33 times that of petroleum fuels. [3] It can also be easily integrated by adapting existing transportation and energy systems, thereby reducing global pollution. [4-6] Today, most of the hydrogen used in industry comes from fossil resources, and in 2015, 48% of hydrogen was from natural gas, 30% from oil, and 18% from coal. [7], hydrogen production from fossil energy is accompanied by a large amount of carbon dioxide emissions. The decarbonization of hydrogen production itself is a major challenge in today's energy transition. Hydrogen with a low carbon footprint could significantly reduce energy-related carbon dioxide emissions and help limit global temperature rise to 2° C [7]. At present, low-carbon hydrogen production methods include hydrogen production from fossil resources combined with carbon capture hydrogen production and renewable energy water electrolysis. The former method can quickly and directly realize flexible hydrogen production, and will be the mainstream means of short- and medium-term industrial hydrogen production methods. With the price of renewable electricity falling and the cost of electrolyzers falling, it is believed that the production of hydrogen from water electrolysis will be larger in the long run. The main hydrogen production methods and their development status are introduced below.

2 Hydrogen production method

2.1 Methane steam reforming method

This method refers to the reaction of methane and water steam to produce syngas under high temperature is accelerated by a catalyst. The feed-in natural gas needs to be desulfurized and pretreated, and then the syngas is prepared through reforming reaction. The carbon monoxide in the syngas is converted into hydrogen and carbon dioxide through water gas conversion, and finally, the carbon dioxide is removed by pressure swing adsorption to obtain hydrogen [8]. The process of hydrogen production by methane steam reforming is shown in Figure 1. The main reaction formulas are:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

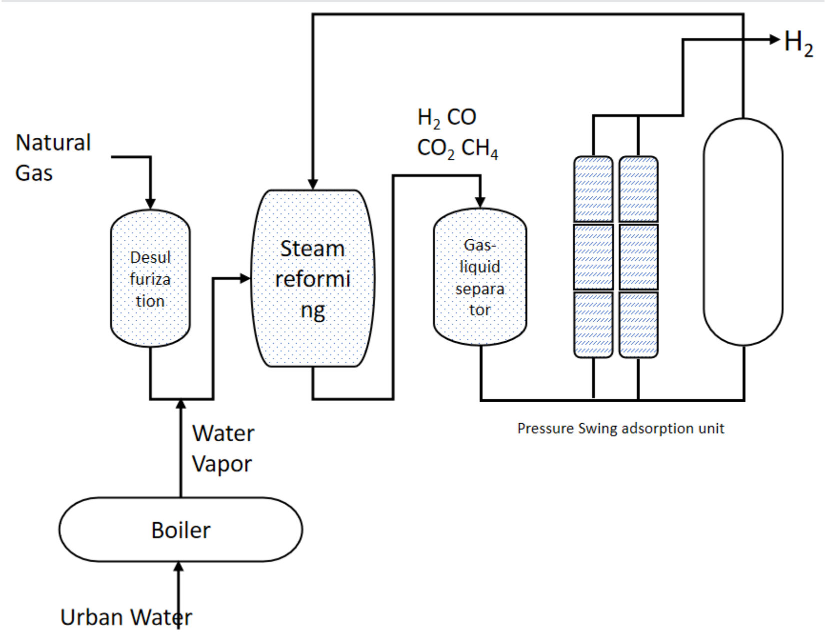

Figure1: Reaction process of methane steam reforming

The price of industrial hydrogen production from natural gas is affected by the distribution of natural gas resource. In the regions with concentrated natural gas resource, the price of hydrogen production is relatively low. Typically, when the price of natural gas is \$0.31 / Nm3, the cost of hydrogen production is estimated to be \$2.37 / kg [9].

The cost comparison of hydrogen production from natural gas in different regions according to the statistics of the International Energy Agency is shown in Figure 2. It can be seen that the cost of hydrogen production from natural gas is affected by a series of technical and economic factors, of which natural gas price and fixed investment cost are the two most important factors. The price of natural gas is the largest cost component, accounting for 45% to 75% of the total cost of hydrogen production. The carbon emission of the methane steam reforming method is 285g of carbon dioxide per kWh, which is equivalent to 9.5kg of carbon dioxide per 1kg of hydrogen produced [11].

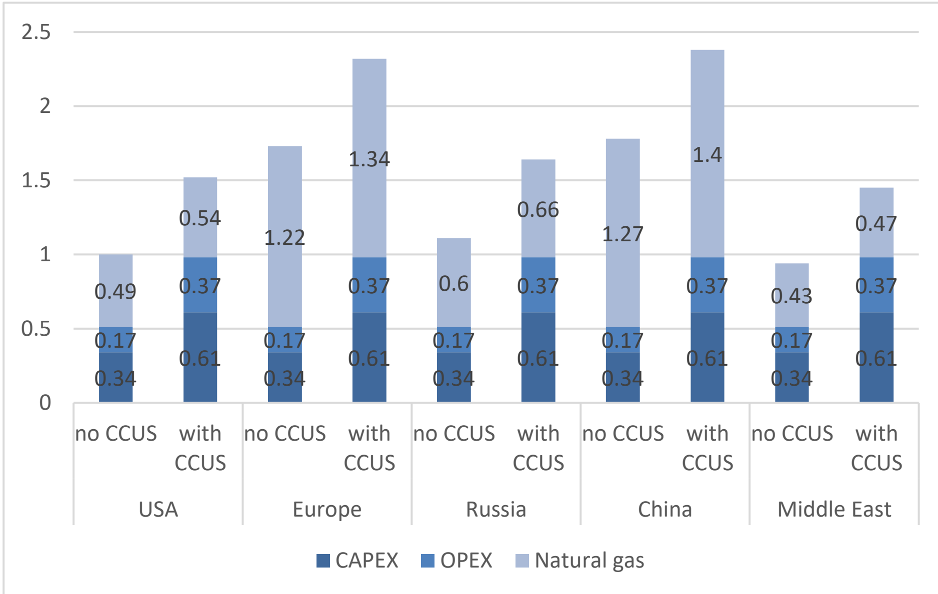

Figure 2: Comparison of hydrogen production cost of natural gas in different regions (unit: USD / kgH) [10]

2.2 Coal gasification

This method refers to the reaction of coal with oxygen and water steam under high pressure to produce carbon monoxide, carbon dioxide and hydrogen. First, when air comes into contact with the coal, the coal is partially oxidized to produce carbon dioxide gas through traditional combustion reaction. Then, the carbon dioxide reacts with the rest of the carbon in the coal to form carbon monoxide. Finally, the carbon monoxide in the gas stream further reacts with water steam to produce hydrogen and carbon dioxide. The reaction formulas are as follows:

$$C + O_2 \rightarrow CO_2$$

$$C + CO_2 \rightarrow 2CO$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

The cost of hydrogen production from coal is lower than that from natural gas. When the price of coal is $94.32 / ton, the cost of hydrogen production from large-scale coal gasification is $1.94 / kg. For example, in areas rich of coal resources, when the coal price is reduced to USD31.44 / ton, the cost of hydrogen production can be reduced to $0.60 / kg [9].

In order to reduce the carbon emissions in the process of hydrogen production from fossil energy, the future hydrogen production from fossil energy must be carried out in conjunction with CCUS. CCUS, the full name of Carbon capture, utilization and storage, refers to the capture of carbon dioxide from fuel combustion or industrial processes, through ships or Pipelines transport this carbon dioxide and use it as a resource to create valuable products or services, or store it permanently in geological formations deep underground. In 2020, two new fossil energy hydrogen production projects in cooperation with CCUS were put into operation in Canada, and the number of projects operating globally has increased to 16, with a total low-carbon hydrogen production capacity of more than 0.7 Mt [12].

2.3 Water electrolysis

The principle of hydrogen production by water electrolysis is to connect the two electrodes in the water to the power supply in an electrolytic cell to conduct electricity. When a sufficiently high voltage is applied, the water is decomposed into hydrogen and oxygen at the cathode and anode respectively. In order to enhance the conductivity of water, acidic or solid polymer electrolytes are usually used. Different electrolytes lead to different charge carriers in water, such as H^+, OH^-, O^{2-}, etc. The reaction process of electrolytic water is shown in Figure 3. No matter what electrolyte is used, the total reaction formula is the same:

$$2H_2O + electricity + \hbar eat \rightarrow 2H_2 + O_2$$

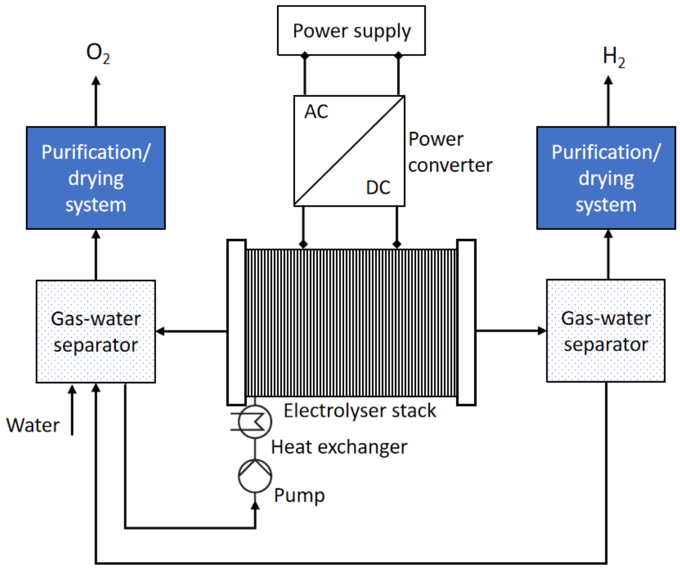

Figure 3: Schematic diagram of electrolytic water

At present, the total capacity of electrolyzers in the world has been announced to be more than 1GW[13]. According to the different electrolytes, water electrolyzers can be divided into alkaline water electrolyzers (AEL), proton exchange membrane Solid oxide electrolyzer (SOEL), the total cost of AEL hydrogen production is about $4.70/kg, which is much higher than the cost of traditional fossil fuel hydrogen production [14]. Due to high procurement costs and depreciation costs, PEMEL's hydrogen production cost reached $6.18/kg. At present, the fixed cost of the hydrogen electrolyzer is about $826.91/kW, and the cost of hydrogen production from wind power is about $3.48/kg when the wind power levelized kWh cost is relatively high (about $39.38/MWh). When the cost of electricity (LCOE) is low (about $19.69/MWh), it is about 16 yuan/kg, that is to say, as far as the current fixed investment cost of hydrogen electrolyzers is concerned, only when the wind level standardization cost of electricity is the lowest , the hydrogen produced by it is price-competitive. The International Renewable Energy Agency pointed out that it is expected that in 2050, the fixed investment cost of hydrogen electrolyzers will be as low as $196.88/kW, and the price of wind power electrolysis hydrogen will drop to $1.35 under the lower wind power levelized kWh/kg [10]. The volatility of renewable resources makes the price of electrolytic hydrogen production highly regionally dependent. Compared with wind or solar energy in developed countries and regions, the price of hydrogen production by electrolysis will be more advantageous.

3 Challenges and prospectives

China is the largest hydrogen producer in the world, with an annual hydrogen production output of about 33 million tons. Both the methane steam reforming method and the coal gasification hydrogen production method produce hydrogen from fossil fuels, that is, non-renewable energy. Such Hydrogen is also known as grey hydrogen, and the hydrogen produced by the fossil energy hydrogen production method with CCUS is called blue hydrogen, which makes the fossil energy-based hydrogen production process carbon neutral, which can significantly reduce industrial production at a lower cost. carbon emissions, accelerating the transition of society to green hydrogen. The so-called green hydrogen is the hydrogen produced by the use of renewable energy to generate electricity and electrolyzed water. Among various hydrogen production methods, PEMEL has strong dynamic response capability and is well coupled with renewable energy sources such as wind energy and solar energy. At this stage, it is considered to be the main technical direction of hydrogen production from renewable energy in the future.

4 Conclusion

Renewable feedstocks and sustainable energy sources for hydrogen production, replacing traditional fossil fuels and current power systems, will make it possible to realize the so-called hydrogen economy, the main goal of which is the large-scale production of hydrogen using readily available energy sources, to replace the current electricity economy based on fossil fuels. To build a hydrogen economy, along with hydrogen production, storage and transportation, and distribution, supporting strategic policies. This not only has a great impact on the development of hydrogen fuel cell vehicles, but also provides a possible solution to achieve a zero-emission society.

Acknowledgments

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