

Hydrogen energy industry development and the research progress of hydrogen production technology

Wenbo Jia

Shandong Vocational and Technical University of International Studies, Rizhao, Shandong, 250100, China

ABSTRACT

Hydrogen energy, as a key aspect of global energy transformation, is increasingly gaining attention in the energy sector. This paper provides an overview of the development background, current status of the hydrogen energy industry, and advancements in hydrogen production technology research. Hydrogen energy, with its clean, efficient and renewable characteristics, is of great significance for promoting the adjustment of energy structure and realizing low-carbon development. At present, the hydrogen energy industry at home and abroad shows a trend of rapid development, with key technologies such as significant progress in Hydrogen generation, storage, and distribution. This paper analyzes the development principles, objectives and key technology fields of hydrogen energy industry, and discusses the principles, advantages and disadvantages and development trends of various Hydrogen production methods such as Water electrolysis and biological methods for hydrogen production.

KEYWORDS

Hydrogen energy industry; Hydrogen production technology; Water electrolytic hydrogen production; Biological hydrogen production; Low cost green hydrogen production; Energy transformation

1 Introduction

With the continuous growth of global energy demand and the increasing awareness of environmental protection, hydrogen energy, as a clean, efficient and renewable form of energy, is gradually attracting wide attention from countries around the world. Its unique high calorific value, zero emission characteristics, and flexible conversion capability in the energy system make hydrogen energy a key player in the worldwide energy shift. At present, Hydrogen energy is extensively applied in transportation, electric power, Industry and various other sectors. Governments are also actively Advancing the growth of the hydrogen energy sector. By providing policy support and capital investment, to accelerate the development, research, and application of hydrogen energy technology. Based on this, this paper systematically combs and analyzes the academic literature, policy reports and industry data on hydrogen industry at home and abroad, and has a comprehensive and in-depth understanding of the macro development trend and micro technical details of hydrogen industry. At the same time, combined with the specific hydrogen energy project cases, the practical application and the potential for growth in the hydrogen energy industry is thoroughly explored.

2 Development status of hydrogen energy industry at home and abroad

Internationally, the development of the hydrogen energy industry has been highly valued. As a sustainable and clean energy carrier, hydrogen energy helps to solve the energy crisis, global warming, environmental pollution and other problems. Currently, many countries have included hydrogen energy as a key component of their national energy systems. More and more countries have responded to the research and suggestions, and have formulated and implemented the hydrogen energy development strategies, and actively promoted the innovation and industrial application of hydrogen energy technology by increasing the investment in research and development.

Domestically, China also places significant emphasis on the development of hydrogen energy and incorporates it into its national energy development strategy. The government has implemented a range of policies and measures to vigorously support the research and development, demonstration and promotion of the hydrogen energy industry. Driven by the policy, Chinas hydrogen energy industry has initially formed a complete industrial chain, covering many links such as hydrogen production, hydrogen storage, hydrogen transportation and application. In terms of hydrogen production and hydrogen storage, scholar Wang Xiaohui proposed in 2024 that converting renewable energy into hydrogen and storing it underground is an effective strategy to solve the problem of volatility. Hydrogen production from water and fossil fuels and underground storage is currently the best mass production and storage program^[1]. In the technology and development of water electrolysis, scholar Chen Ying analyzed the current situation of various hydrogen production technologies of water electrolysis in 2024, and discussed the future development trend, to provide guidance for the research and development and commercialization of related technologies^[2]. At the same time, in the gas hydrogen production and offshore wind hydrogen production, scholars liu in 2024 elaborated the gas hydrogen

production process, including gas preheating, catalytic conversion, heat recovery and transformation steps, design the special furnace, avoid furnace tube at low load temperature, prolong the service life, and by strengthening insulation to reduce the energy consumption of low load^[3]. Scholar RoShan pointed out in 2024 that PEM hydroelectrolysis hydrogen production technology can be better coordinated. The power supply with large output power fluctuation can be developed in the direction of high power and low cost in the future, which is more compatible for offshore wind power hydrogen production projects^[4]. The hydrogen energy industry is also exhibiting a trend of diversification. In addition to the traditional energy companies, more and more technology companies and startups are also joining in the research and development and application of the hydrogen energy industry. Through technological innovation and model innovation, These companies have driven the ongoing advancement of hydrogen energy technology and cost reduction, making the application scope of hydrogen energy more widely. Reporter Zhang Shengjie mentioned in 2024 that the new departure electrocatalytic technology, compared with the traditional Claus process, can reduce the dependence on high temperature and high pressure operation, thus may reduce energy consumption and related security risks; realize the complete elimination of hydrogen sulfide, and recycle the utilization of hydrogen and sulfur; solve the problem of electrocatalysis, and broaden its application scope^[5].

3 Introduction to hydrogen production technology

3.1 Hydrogen production technology by electrolysis of water

Water electrolysis technology is a clean and efficient hydrogen production mode. Its development process and technological progress play an irreplaceable role in the promotion of the whole hydrogen energy industry. Hydrogen hydrogen electrolysis technology includes alkaline water electrolytic cell (AWE), Proton exchange membrane electrolyzer (PEM), alkaline anion exchange membrane electrolyzer (AEM), and solid oxide electrolyzer (SOE). AWE is one of the most commonly used hydrogen production technologies through water electrolysis. The PEM electrolytic cell is famous for its rapid response, wide power regulation range and strong overload capacity. AEM technology is still in the demonstration stage, it uses a solid polymer as a diaphragm, and the electrolyte is also a solid polymer. The SOE uses solid ceramics as the electrolyte, and the working medium is water vapor.

In terms of cost, with The widespread application of water electrolysis hydrogen production technology and the improvement of the industrial chain, its production cost is gradually reduced. On the one hand, the manufacturing cost of key equipment such as electrolytic cell is decreasing driven by scale effect.

In terms of stability, researchers have improved the stability and reliability of water electrolysis by improving the process conditions and operation process of water lysis. For example, by optimizing the formulation and concentration of the electrolyte, side reactions and impurity generation in the electrolytic process can be reduced, thus improving the purity and quality of hydrogen.

Currently, water electrolysis for hydrogen production is extensively used in energy storage, fuel cells, and other sectors. As a critical technology in the hydrogen energy industry, advancements and expansion in efficiency, cost, and stability are crucial for advancing the overall growth of the hydrogen energy sector.

Table1 Table of technology and process of hydrogen production by electrolytic water

order number	Content description	define
1	Principle of electrolysis of water for hydrogen production reaction	Hydrogen and oxygen are decomposed by electrolytic water. Electrolysis of water is a chemical process that decomposes water (H ₂ O) into hydrogen (H ₂) and oxygen (O ₂) by direct current electricity.
1.1	chemical equation	$2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$
1.2	Requirements	Adequate supply of electricity, and appropriate electrolytes (Such as sulfuric acid, sodium hydroxide, and others.) are needed to increase the conductivity of the water.
2	The working principle of the electrolytic cell	The electrolytic cell is composed of the anode, cathode and electrolyte. When the direct current passes through the electrolytic cell, the water molecules produce oxygen at the anode, oxygen is produced, and at the cathode, hydrogen is produced.
2.1	anode reaction	$2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$ (water molecules lose electrons at the anode to generate oxygen)
2.2	cathode reaction	$4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2$ (water molecules obtain electrons at the cathode to generate hydrogen)
2.3	Electrolytic pool composition	Including anode (positive), cathode (negative) and electrolyte. Commonly used electrolyte has sulfuric acid, sodium hydroxide and so on.
2.4	electrolytic efficiency	Electrolysis efficiency is influenced by factors such as electrolyte concentration, current density, and temperature. Optimizing these conditions improves the electrolysis efficiency.

3.2 Biomass hydrogen production technology

As an emerging method of hydrogen production, biomass hydrogen production technology has garnered significant attention in recent years.

The technology mainly uses agricultural waste, forestry waste, municipal household waste and other biomass resources, to convert these wastes into hydrogen through microbial fermentation or thermochemical conversion process. This hydrogen production method not only helps to solve the energy crisis, but also can realize the resource utilization of waste, which has significant environmental benefits.

In terms of hydrogen production by microbial fermentation, the researchers have improved the hydrogen production efficiency and hydrogen purity of biomass by screening and cultivating efficient hydrogen production microorganisms and optimizing the fermentation process conditions.

At the same time, for different types of biomass raw materials, the researchers have also developed corresponding pretreatment technologies and fermentation processes to achieve efficient utilization of raw materials and stable production of hydrogen.

For example, under anaerobic conditions, certain bacteria are able to convert organic substances (such as sugars) into hydrogen and other by-products, as follows:

$$\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} \rightarrow 12\text{H}_2 + 6\text{CO}_2$$
 In this process, the glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) is decomposed by microbial metabolism into hydrogen (H_2) and carbon dioxide (CO_2).

In terms of thermochemical conversion to produce hydrogen syngas, biomass is converted into hydrogen-rich syngas mainly through gasification, pyrolysis and other technical means.

The current biomass hydrogen production technology still faces some challenges, such as technology maturity, economic cost and marketing problems, but its great potential in sustainable development and environmental protection makes the research and application of this technology very broad.

The advancement of biomass hydrogen production technology will also drive the coordinated development of related industries, such as biomass energy industry, environmental protection industry, etc.

Through the construction of a sound industrial chain and innovation system, the company can promote the large-scale application and industrialization development of biomass hydrogen production technology, so as to make valuable contributions to optimizing the global energy structure and addressing climate change.

3.3 Other hydrogen production technologies

In the vast world of the hydrogen energy industry, the diversity of hydrogen production technology has injected endless vitality into this field.

In addition to the well-known water electrolysis and biomass hydrogen production technologies, other hydrogen production methods also play an essential role.

These technologies, with their unique principles and applicable scenarios, jointly promote the progress and development of the hydrogen energy industry.

Fossil fuel reforming hydrogen production technology has been extensively used in industrial production with its mature technology route and relatively low cost.

Although this process will produce greenhouse gas emissions, but it still has a certain market competitiveness under the existing energy structure.

Compared with the fossil fuel reforming hydrogen production technology, the light solution of water hydrogen production technology shows a more environmentally friendly characteristics. The technology, which uses solar energy to drive a photocatalyst to decompose water molecules to generate hydrogen and oxygen, is considered to be a sustainable hydrogen production method with great potential.

There are also some emerging hydrogen production technologies such as nuclear energy hydrogen production, thermochemical cycle hydrogen production.

These technologies, with their unique principles and potential advantages, bring new possibilities for the development of the hydrogen industry.

Nuclear hydrogen production technology, for example, uses the hot heat generated by nuclear reactors to decompose water molecules and thus produce large amounts of hydrogen.

The technology has the advantages of high energy density and no carbon emission, but it also faces problems such as nuclear safety and nuclear waste disposal.

Thermochemical cycle hydrogen production technology converts water and heat into hydrogen and oxygen through a series of chemical reactions, which can enable the efficient use of energy and minimize waste emissions.

Table 2 Brief list of other hydrogen production technologies

Hydrogen production mode	response equation	temperature range (°C)	Pressure range (MPa)	catalytic agent	Other conditions	Hydrogen production efficiency
Natural gas reforming to produce hydrogen	$\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow 4\text{H}_2 + \text{CO}_2$	700-900	1-3	nickel-based catalyst	High temperature promotes the reaction rate, and appropriate pressure promotes the reaction to proceed	tall
Coal gasification hydrogen production	$\text{C} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2$ $\text{C}_n\text{H}_m + n\text{H}_2\text{O} \rightarrow n\text{CO} + \frac{m}{2}\text{H}_2$	700-1000	Normal pressure to medium pressure	Iron-based or cobalt-based catalysts	High temperature improves the gasification efficiency, and the catalyst selection is important	centre
Oil coking hydrogen production	$\text{C}_n\text{H}_m + n\text{H}_2\text{O} \rightarrow n\text{CO} + \frac{m}{2}\text{H}_2$	800-1000	Normal pressure to medium pressure	Similar to coal gasification for hydrogen production catalyst	High temperature, appropriate pressure and catalyst selection key	centre

4 Conclusion and outlook

This paper explores the development status of the hydrogen energy industry and various hydrogen production technologies. The study reveals that hydrogen energy, as a clean, efficient, and renewable energy source, is gaining global attention and is being applied in sectors such as transportation, electricity, and industry. Regarding hydrogen production technology, this paper discusses water electrolysis, biomass hydrogen production, and other methods of hydrogen production. Different hydrogen production technologies have their own unique principles and applicable scenarios, which jointly promote the progress and growth of the hydrogen energy industry.

Looking into the future, the policy support and financial investment of the government, and the continuous efforts of researchers will promote the wide application of hydrogen production technology, and contribute positively to optimizing the global energy structure and addressing climate change.

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