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An Overview of the Key Technology of Renewable Energy Multi-Energy Complementary Hydrogen-Storage-Transport

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Abstract: Hydrogen Energy is the chemical energy that results from the chemical reaction of hydrogen and oxygen. It is also an environmental-friendly, safe and clean energy which can provide sustainable resources. Nowadays, hydrogen energy has become more and more popular due to its advantages. Therefore, the technologies of hydrogen production, transport and storage are obviously significant. To begin with, according to prior research, this section examines the benefits and advantages of hydrogen energy for humanity, as well as its developmental trajectory. Furthermore, it highlights the essential technologies of the complementary multi-energy hydrogen production system, detailing methods capable of generating hydrogen. The passage involves different kinds of energy production technology that help produce hydrogen energy. Lastly, the transportation and storage technology of hydrogen energy is summarized, and the paragraph also generalizes its disadvantages and outstanding features. This passage provides references for the development of renewable energy complementary systems controlling hydrogen technology.

Keywords: Renewable energy, Hydrogen production, Technology of energy production, Transportation and storage, Multi-energy complement

1. Introduction

The development of hydrogen energy offers numerous benefits, including its clean and environmentally friendly nature, as its combustion only produces water without harmful emissions like carbon dioxide or nitrogen oxides. This makes it a nearly pristine energy source that can help address global climate change and pollution. Additionally, hydrogen is abundant and renewable. However, the industry currently faces challenges in production technology, storage and transportation, and fuel cell costs.

In greater detail, the passage concludes with techniques that better help solve the problem of hydrogen production and management. By evaluating various forms of production and transport mechanisms, it offers multiple strategies for hydrogen generation and transition that minimize energy loss.[1].

Hydrogen generation utilizing renewable energy electricity sources, for example, with the continuous advancement and large-scale application of renewable energy technologies, the cost of power generation has gradually decreased, thereby reducing the cost of hydrogen production [2]. In recent years, the expenses associated with solar photovoltaic and wind energy generation have consistently decreased, allowing the overall costs of hydrogen production from renewable energy

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sources to increasingly approximate or even fall below those of conventional hydrogen production techniques. [3]Through the research of materials science, semiconductor technology and optical design, the conversion efficiency of solar photovoltaic cells and wind turbines is improved, and the cost of power generation is reduced. For example, the development of new solar photovoltaic materials, such as perovskite solar cells, has the potential for higher conversion efficiency and lower cost. Also, solar photovoltaic and wind power are clean energy sources that produce almost no greenhouse gases in the process of generating electricity. The large use of these two energy sources can significantly reduce dependence on fossil fuels, thereby reducing greenhouse gas emissions such as carbon dioxide and mitigating global climate change problems. What is more, they are not affected by international energy market fluctuations and geopolitical factors. The development of these two energy sources can increase the diversity of energy supplies and improve the country's energy security.[4]

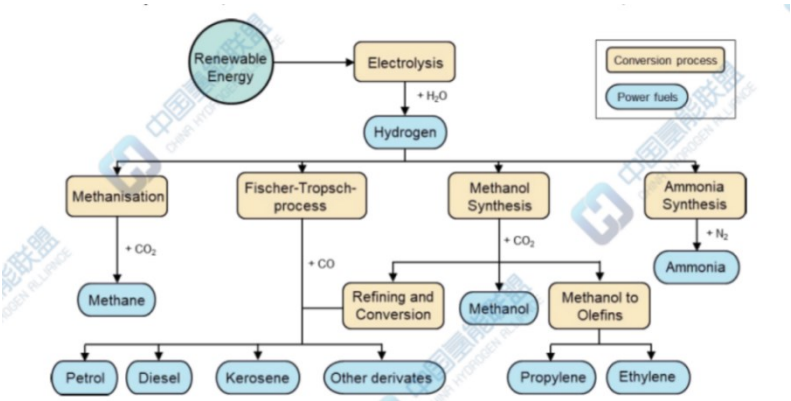

Figure 1: The simplified process of converting electricity and/or hydrogen into power fuel and its main application areas [5]

2. The key technologies of multi-energy complementary hydrogen production system

2.1. Energy supply and integration technology

Utilizing sustainable energy can effectively address global pollution and the energy crisis. Coordinated management of diverse energy sources and optimized allocation strategies ensure a stable supply. Various energy types can be efficiently harvested: solar energy converts to electricity via the photovoltaic effect, while hydropower generates electricity through flowing water driving turbines. These technologies continuously evolve, enhancing energy harvesting efficiency while reducing costs and ecological impacts. In practical implementations, the optimal integration of technologies is typically determined based on the distinct energy resources available and the specific requirements at hand.[6]

2.2. Electrolysis hydrogen production technology

The advancement of technology has propelled solid oxide water electrolysis for hydrogen production (SOEC) towards large-scale development, aiding the pursuit of peak carbon neutrality. China's first automated SOEC production line, with a capacity of 100 MW annually, is now operational. Currently, alkaline electrolytic water, proton exchange membrane electrolysis (PEM), and SOEC are the three primary hydrogen production technologies. Each method offers unique advantages suited to different applications, promoting diverse technological pathways for industrial advancement. SOECs are particularly advantageous due to their lack of precious metal catalysts, resulting in significant cost savings and improved efficiency. However, the pertinent industrial

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supply chain remains underdeveloped, necessitating ongoing technological advancements and the establishment of an optimal ecological industrial chain framework.[7]

Table 1: Comparison of three typical hydrogen production technologies[1]

Genre	Basic electrolytic tank	Proton exchange electrolytic tank	Solid oxidation electrolytic tank
electrolytic efficiency	60%~75%	70%~90%	85%~100%
performance characteristic	Fast start and stop	Faster start and stop	inconvenience
characteristic	The most mature, the highest degree of commercialization, low cost	Renewable energy has strong adaptability, no pollution, high cost and low degree of industrialization	Part of the electric energy is replaced by heat energy, the conversion efficiency is high, and the industrialization has not yet been realized

2.3. Safety and environmental technology

Hydrogen production equipment must be installed in well-ventilated areas to facilitate timely outdoor discharge of hydrogen. Ventilation systems should meet the equipment's requirements for indoor air circulation. Given that hydrogen is flammable and explosive, strict measures must be taken to prevent fire sources during production. Additionally, wastewater, gas, and other pollutants generated must be properly treated and not discharged indiscriminately; wastewater should meet standards post-treatment, and waste gas must undergo purification. Most importantly, hydrogen production equipment must adhere to relevant standards and specifications, ensuring high quality and reliability, with rigorous testing and certification for stable operation within specified pressure, temperature, and flow ranges.

2.4. System integration and optimization technology

Overall architecture design and optimization of multi-energy complementary hydrogen production system to improve energy efficiency and system reliability. In greater detail, thermal management technology, efficient use of the heat generated by the system, improve overall energy efficiency. It should be considered when managing and scheduling the input of multiple energy sources to achieve efficient energy utilization and stable operation of the system. It have developed an advanced energy management system designed to facilitate real-time monitoring and scheduling of various energy sources, ultimately promoting optimal energy efficiency and ensuring consistent operational stability.[7] Advanced sensors and data analytics enable real-time monitoring and prediction of energy output, facilitating timely adjustments in energy input and output. Additionally, optimizing hydrogen production and energy storage control systems enhances automation and accuracy. Implementing advanced control algorithms and automated equipment allows for automated hydrogen production and intelligent energy storage management.

2.5. Intelligent control and monitoring technology

The intelligent control system plays a crucial role in the multi-energy complementary hydrogen production system. It can achieve precise regulation of energy input, hydrogen production process and output, ensuring the system operates efficiently, stably and safely. Various sensors are installed to monitor the input parameters of solar, wind, water, biomass and natural gas in real time, such as

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light intensity, wind speed, water flow speed, biomass quality and natural gas flow. For example, Figure 2 shows how this technology works in collecting information.

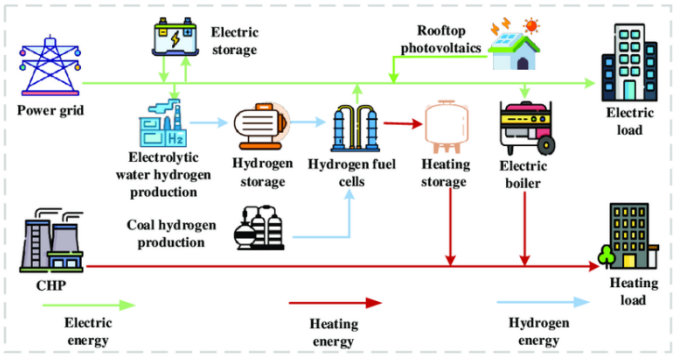

Figure 2: Structure of electricity and hydrogen energy system[8]

In short, the intelligent control system is the core component of the multi-energy complementary hydrogen production system, which can realize the accurate regulation of energy input, hydrogen production process and output, and improve the efficiency, stability and safety of the system. By continuously optimizing the design and implementation of intelligent control systems, more reliable technical support can be provided for the large-scale application of hydrogen energy.

3. Transport and storage technology of hydrogen energy and their advantages and disadvantages

3.1. High temperature gaseous transport and hydrogen storage

This method involves the compression of hydrogen into a specialized storage tank under high pressure, thereby enhancing the hydrogen density per unit volume. [9]According to different application scenarios, it is divided into fixed hydrogen storage and mobile hydrogen storage. Fixed hydrogen storage is mainly used in hydrogen refueling stations, emergency power supply, backup power supply, and hydrogen energy storage. Mobile hydrogen storage is transported primarily by long tube trailers. Its benefits are that it is a simple equipment structure with relatively low costs and a fast speed of hydrogen charging and discharging, so it can meet the demand of for fast hydrogenation and adapt to a wide range of temperatures. However, this technology also has disadvantages the mass volume density is small and the hydrogen storage efficiency is not very high, safety is also a problem: high pressure storage may leads to explosion risk. Hydrogen has a tendency to induce a phenomenon known as "hydrogen embrittlement" in the metals used for hydrogen storage vessels. [10]

3.2. Low temperature liquid transport and storage of hydrogen

This method cools hydrogen to -253°C for liquefaction and storage in an adiabatic unit. It offers several advantages: liquid hydrogen has a high energy density, reaching 70.78 kg/m³—about 850 times denser than hydrogen at standard conditions. Its volumetric energy density is roughly three times that of 35 MPa gaseous hydrogen and 1.8 times that of 70 MPa gaseous hydrogen. Additionally, it features high vaporization purity and low storage pressure. However, the liquefaction process is energy-intensive, consuming about 30% of the transported hydrogen's energy, equating to 7-10 kWh per kilogram. Furthermore, the hydrogen storage vessel requires excellent insulation due to the low boiling point and significant temperature differential with the

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environment. Special containers are necessary to withstand ultra-low temperatures, resist freezing and pressure, and maintain strict adiabatic conditions, indicating that costs must still be reduced.

3.3. Pipeline transport of hydrogen energy

Hydrogen is transported via underground or subsea pipelines, enabling long-distance transport, a key advantage. These pipelines are not constrained by geography, facilitating transnational and regional resource allocation and enhancing energy efficiency. Additionally, hydrogen's high density necessitates pressurized storage, which the pipelines provide, effectively minimizing safety risks. This method also reduces pollution from raw material loading, promoting environmental protection and sustainability. However, the shortages also exist. Pipeline transportation is suitable for large-scale, long-distance transportation with low energy consumption per unit, but there is a high construction cost. The cost of pipeline hydrogen transportation mainly comes from the depreciation and maintenance costs of pipes which are positively related to the transportation distance. Currently, the economic benefits of hydrogen transport via pipelines are not clearly evident, especially in the absence of widespread hydrogen refueling stations, which tend to be sparsely distributed.. [10, 11]The construction and operation of hydrogen energy pipelines are faced with many technical challenges, such as how to ensure the safe operation of the pipeline, how to solve the problem of hydrogen storage and so on. Hydrogen energy pipelines require corresponding infrastructure support, such as filling stations and gas storage. The construction of these facilities may be affected by regional resources, policies and other factors. At present, domestic hydrogen energy pipeline transportation is still in the development stage, but it has not been widely used as the main mode of hydrogen energy storage and transportation.

3.4. Hydrogen storage and transportation in solid state

This approach entails that at standard temperatures, hydrogen undergoes a chemical reaction with the alloy, facilitating the ingress of hydrogen atoms into the metal lattice for storage. Furthermore, by elevating the ambient temperature of the alloy, hydrogen can be subsequently released. Its low cost trait is outstanding. Solid state hydrogen storage does not require the use of high pressure or low temperature equipment, which can significantly reduce operating costs. For example, the solid-state hydrogen storage tank addresses the spatial constraints imposed by high-pressure hydrogen cylinders and the cryogenic requirements of liquid hydrogen systems. Additionally, users are not obligated to develop hydrogenation infrastructure, leading to a reduction in overall energy consumption and operating expenses to some degree.. The second advantage is the abundant resources. China's annual magnesium production accounts for more than 85% of the total global production, providing a sufficient material source for solid-state hydrogen storage.[11, 12] Third, long service life. 3000 cycles of hydrogen absorption and discharge have no obvious attenuation. However, solid-state hydrogen storage and transportation also have some shortcomings: at present, solid-state hydrogen storage has not been widely popularized due to high cost, although it is safe and the unit transport volume is large. For example, the high cost of hydrogen storage in solid metals limits its application in some fields.

4. Conclusion

The article provides a comprehensive overview of the advancements in hydrogen production, while also thoroughly examining the advantages and limitations associated with the transportation and storage of hydrogen energy. Now, the technologies of hydrogen energy production, transportation and management are still in a developing state. The transportation and storage technologies of hydrogen energy are diverse, and each technology has its unique advantages and disadvantages.

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[13]High-pressure gaseous storage and transportation technology for hydrogen energy is mature and has a fast hydrogen charging and discharging speed, but the hydrogen storage density is not high and the requirements for containers are high; low-temperature liquid storage and transportation of hydrogen energy have a high volumetric density, [14]but the liquefaction cost is high and the requirements for thermal insulation performance are stringent; solid-state storage and transportation of hydrogen energy has a high hydrogen storage density and good safety, but the cost is relatively high; organic liquid storage and transportation of hydrogen energy has a large hydrogen storage density and relatively high safety, but the technical operating conditions are harsh; pipeline transportation of hydrogen energy is suitable for long-distance transportation and has high safety, but the construction cost is high and it faces technical difficulties. [15]In practical applications, it is necessary to select a suitable hydrogen energy transportation and storage technology according to different needs and conditions to promote the development of the hydrogen energy industry. Furthermore, the multi-energy complementary hydrogen production system represents an innovative hydrogen generation technology that holds significant potential for various applications.[16] Through reasonable overall architecture design and optimization, it can improve hydrogen production efficiency, reduce costs and enhance system stability, providing strong support for the large-scale application of hydrogen energy.

References

[1] *Li, Z., Zhang, R., Sun, H., et al. (2021). Renewable energy can complementary system - transporting hydrogen storage key technical review. Journal of Electrotechnics, 4(3), 446-462.*

[2] *Liang, D., Zong, Z., Song, J., et al. (2024). Meter and the efficiency of life more heap of electrolytic hydrogen production system operation optimization. Journal of Coal, 1-11.*

[3] *Yang Jing-Wei, Zhang Ning, Wang Yi, & Kang Qing-Qing. (2018). Multi-energy systems for renewable energy consumption: Review and prospect. Automation of Electric power Systems, 42(4), 11-24.*

[4] *Chen J H, & Yang Y M. (2007). Development status and prospect of wind power/energy generation. Journal of Guangdong University of Technology, 24(03), 1-5.*

[5] *Wen Yunfeng, Yang Weifeng, Wang Ronghua, Xu Weiting, Ye Xi, & Li Ting. (2020). Review and prospect of building 100% renewable energy power system. Proceedings of the CSEE, 40(6), 1843-1856.*

[6] *China hydrogen union (2023), the hydrogen storage and transportation technology review on http://m.toutiao.com/group/7297076574892442124/*

[7] *Pan G S, Gu W, Zhang H Y, & Qiu Y. (2020). Electric hydrogen energy system for high proportion of renewable energy consumption. Automation of Electric Power Systems, 44(23), 1-10.*

[8] *Guo Bow-wen, Luo D, & Zhou Hong-Jun. (2021). Research progress of renewable energy electrolytic hydrogen production technology and catalysts. Advances in Chemical Engineering, 40(6), 2933-2951.*

[9] *China Energy News (2023) Breakthrough in the mainstream technology of hydrogen production from electrolytic water https://www.toutiao.com/article/7228885245498819132/?upstream_biz=doubao&source=m_redirect&wid=1726370519880*

[10] *Locke capital Shi Songpo (2023) import dependence on high economic costs, independently controllable become a development path to https://www.toutiao.com/article/7194731929512444420/*

[11] *Li Yuxing, Liu Cuiwei, Peng Haoping, Han Hui, Zhu Jianlu, Song Guangchun, & Wang Cailin. (2024). Current situation and challenge of hydrogen energy transportation mode and technology. Prospective Technology, 3(2), 81.*

[12] *Blaabjerg, F., Iov, F., Kerekes, T., Teodorescu, R., & Ma, K. (2011, February). Power electronics-key technology for renewable energy systems. In 2011 2nd Power Electronics, Drive Systems and Technologies Conference (pp. 445-466). IEEE.*

[13] *Sorensen, B. (2004). Renewable energy. Elsevier.*

[14] *Jacobsson, S., & Johnson, A. (2000). The diffusion of renewable energy technology: an analytical framework and key issues for research. Energy policy, 28(9), 625-640.*

[15] *Turkenburg, W. C., & Faaij, A. (2000). Renewable energy technologies (pp. 219-72). UNDP/UNDESA/WEC: Energy and the Challenge of Sustainability. World Energy Assessment. New York: UNDP, 219-272.*

[16] *Zobaa, A. F., & Bansal, R. C. (2011). Handbook of renewable energy technology. World Scientific.*