

Application of Green Technology in New Energy Production: Synergistic Innovation of Hydrogen Energy, Photovoltaics, and Carbon Capture

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Abstract. With increasing global emphasis on environmental protection, the drawbacks of traditional chemical technologies—such as high energy consumption, pollution, and resource waste—have become prominent. Green chemical technology addresses these issues by maximizing resource efficiency and emphasizing atom economy. This study explores key green chemical technologies in the renewable energy sector, focusing on hydrogen energy and carbon capture. This paper finds that hydrogen production via water electrolysis (alkaline, PEM, and SOE methods) enables zero-emission energy storage and high-purity industrial applications, while innovations in catalysts and membrane materials enhance efficiency and cost-effectiveness. Carbon capture technologies (chemical/physical absorption, membrane separation, and cryogenic methods) are analyzed for their industrial applications, with advancements in low-energy absorbents and hybrid systems improving feasibility. Additionally, CO₂ utilization in chemical synthesis, construction materials, and agriculture demonstrates its circular economy potential. This research highlights the role of green chemical technologies in achieving carbon neutrality and promoting sustainable industrial development.

Keywords: Green chemical technology, Hydrogen technology, Carbon capture, Renewable energy

1. Introduction

With increasing societal emphasis on environmental protection, the limitations of traditional chemical technologies have become increasingly apparent. Terms such as "high energy consumption," "high pollution," and "resource wastage" are frequently associated with conventional chemical processes, prompting a shift toward greener and more sustainable alternatives. Green chemical technology addresses the issue of resource inefficiency by maximizing material utilization through an emphasis on atom economy, thereby minimizing excess resource consumption.

Among these advancements, hydrogen energy stands out as a pivotal technology in green chemistry. Produced via renewable energy-driven water electrolysis, hydrogen enables the transition from fossil fuels to clean energy, significantly reducing urban carbon emissions. Furthermore, hydrogen storage and its operational flexibility mitigate the intermittency and instability inherent in

renewable energy sources, enhancing the overall resilience of energy systems. Another widely adopted technology in green chemistry is photovoltaics (PV), which harnesses solar energy to generate electricity. As a pollution-free and renewable energy supply, PV technology effectively curbs greenhouse gas emissions and complements hydrogen energy systems. The third technology discussed in this article is carbon capture and utilization (CCU) [1]. CCU facilitates the synthesis of chemicals and the displacement of underground water resources, promoting circular resource utilization [2].

2. Innovation and application of green chemical engineering technology in hydrogen energy preparation

2.1. Hydrogen production technology and application through electrolysis of water

Green chemical engineering technology in hydrogen energy production has been widely applied in the chemical industry due to the sustainability of hydrogen energy technology. The principle is hydrogen production from electrolytes. Hydrogen production through water electrolysis involves splitting water into hydrogen and oxygen through an electrolytic reaction. In an electrolytic cell, water molecules lose electrons at the anode to produce oxygen and simultaneously gain electrons at the cathode to generate hydrogen [3]. There are three main technologies for electrolyzing water: Alkaline electrolyzed water (AWE) uses alkaline electrolytes (such as potassium hydroxide or sodium hydroxide) for electrolysis; Proton exchange membrane water electrolysis (PEM) features high current density and flexible operation, and is often used in projects combined with renewable energy [1]. Solid oxide electrolysis of water (SOE) is carried out at high temperatures, featuring high energy conversion efficiency. These technologies are widely applied in hydrogen energy production, including clean energy production (achieving zero emissions by using renewable energy sources such as solar and wind power for power supply), high-purity hydrogen demand fields (such as semiconductor manufacturing, metallurgy, pharmaceuticals and other industries, where the hydrogen concentration in electrolytic hydrogen production can reach over 99.9%), and energy storage and conversion (converting renewable energy into hydrogen for storage) Solve the intermittent problem of renewable energy [4].

2.2. Green chemical technology innovation - catalyst technology

In the advancement of green chemical technology, the innovation of catalyst technology has become a key breakthrough point for enhancing the efficiency of hydrogen production through electrolysis of water. The development of new catalysts is an important direction in this field, among which the application of rare earth modified catalysts is particularly prominent [5]. This catalyst not only significantly enhances the efficiency of hydrogen production through water electrolysis, but also prolongs the service life of the catalyst itself, reducing the additional costs and resource waste caused by frequent catalyst replacement. Meanwhile, the development of non-precious metal catalysts has also made significant contributions. This type of catalyst effectively reduces the cost in the hydrogen production process, making the electrolytic water hydrogen production technology more economically feasible and paving the way for large-scale commercial application. In addition, precision design is also a major highlight of catalyst technology innovation. Through atomic-level fine regulation, efficient hydrogen production has been achieved. This process not only enhances hydrogen production efficiency but also reduces carbon emissions, making a positive contribution to

environmental protection and embodying the concept of green chemical technology that pursues high efficiency while taking environmental protection into account [6].

2.3. Green chemical technology innovation - optimization of electrolytes and membrane materials

The optimization of electrolytes and membrane materials is another key area of technological innovation in green chemical engineering, which plays a crucial role in enhancing the overall performance of hydrogen production through water electrolysis. Firstly, the development of high-performance electrolytes is one of the core contents of this optimization. The emergence of new electrolytes has greatly enhanced the efficiency and stability of electrolysis, making the hydrogen production process through water electrolysis more efficient and reliable, and better meeting the requirements for hydrogen production quality and stability in different application scenarios. Secondly, the material innovation of proton exchange membranes should not be overlooked either. Through material innovation, not only has the production cost of proton exchange membranes been reduced, but their performance has also been enhanced. This is of great significance for lowering the overall cost of hydrogen production through water electrolysis and improving market competitiveness. When these optimization measures are combined, they not only enhance the technical level of hydrogen production through electrolysis of water, but also significantly improve its economic efficiency and market competitiveness, providing strong support for the wide application of green chemical technology in the new energy field.

2.4. Technical measures for cost reduction

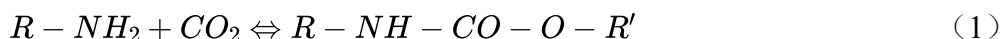
In the development process of green chemical technology, reducing costs has always been an important goal. To achieve this goal, a series of innovative technical measures have been adopted. Among them, the "selective partial reforming" technology is a representative innovation. This technology not only converts biomass into hydrogen but also co-produces high-value chemicals such as acetic acid. This co-production model not only increases the added value of the products but also effectively reduces the cost of hydrogen production, achieving a win-win situation of economic and environmental benefits. In addition, some enterprises have further optimized resource utilization by building a closed-loop system of "hydrogen production - carbon storage - acid production". This closed-loop system realizes the efficient recycling of resources, reduces waste, saves costs, and enhances the economic efficiency and sustainability of the entire hydrogen production system. These cost-cutting measures not only help promote the commercial application of electrolytic water hydrogen production technology, but also provide a strong guarantee for the further development of green chemical technology in the new energy field, making it more competitive in the market.

3. The application of carbon capture technology in the preparation of new energy and technological innovation in green chemical engineering

Carbon capture technology is widely applied in the preparation of new energy. It is divided into five methods: chemical absorption method, physical absorption method, adsorption method, membrane separation method, and cryogenic method. The principle of chemical absorption is to use chemical absorbents to undergo chemical reactions with carbon dioxide, thereby achieving the capture of carbon dioxide.

The reaction process is as follows: Taking organic amines as an example, the amino group (-NH₂) in organic amines can react with carbon dioxide (CO₂). When carbon dioxide comes into contact with organic amines, the lone pair of electrons on the nitrogen atom of the amino group will interact with the carbon atom in the carbon dioxide molecule, forming products such as carbamates (-NH-CO-O-).

The reaction equation can be expressed as:



(Where R and R 'represent organic groups)

3.1. Characteristics of chemical absorption method and physical absorption method and innovations in green chemical engineering technology

Carbon capture technology is widely applied in the preparation of new energy. The chemical absorption and physical absorption are two of the important methods. Chemical absorption method captures carbon dioxide by using chemical absorbents (such as organic amines and alkaline solutions) to undergo chemical reactions with carbon dioxide. It is widely applied in post-combustion carbon capture projects in coal-fired power plants, natural gas power plants and cement plants. Its advantages include high capture efficiency and high purity of carbon dioxide, making it suitable for large-scale applications. However, it has problems such as high energy consumption, high cost and degradation of absorbents. Physical absorption methods rely on the difference in solubility of carbon dioxide in physical adsorbents to achieve separation. Common ones include formaldehyde (Restisol method), polyethylene glycol dimethyl ether (Seroxol method), and methylpyrrolidone (Purisol method). They are mainly applied in fields such as natural gas processing and syngas purification. It has the advantages of stable chemical properties, not easy to degrade and low energy consumption, but it has high requirements for carbon dioxide concentration. For these two absorption methods, green chemical technology innovations include developing low-energy consumption absorbents to reduce regeneration energy consumption, and developing highly efficient catalysts to accelerate the chemical absorption process and reduce the amount of absorbents used, thereby lowering costs. In addition, by optimizing energy-saving processes and coupling technologies, such as integrating with renewable energy-driven and electrolytic water hydrogen production, the overall efficiency of carbon capture projects has been enhanced.

3.2. Characteristics and innovations of membrane separation method

Membrane separation is one of the relatively less mature methods in carbon capture technology. It achieves carbon dioxide separation by taking advantage of the different permeation rates of gases in the membrane. It has the advantages of simple equipment maintenance, low energy consumption and compact equipment, and is suitable for medium and high concentration carbon dioxide gases, such as natural gas decarbonization and syngas. However, the high cost of membrane materials is a limiting factor. To enhance the usability of membrane technology, Green Chemical Technology Innovation is committed to developing membrane materials with higher selective permeability and high-temperature resistance. Meanwhile, by integrating with other carbon capture technologies, the separation efficiency of membrane technology has been further enhanced, and its application potential in the field of carbon capture has been strengthened.

3.3. Characteristics of cryogenic method and utilization of carbon dioxide resources

The cryogenic method is another approach in carbon capture technology, but due to its high energy consumption and complex equipment, it has not been widely applied like chemical and physical absorption methods. The basic principle of cryogenic treatment is to separate carbon dioxide at low temperatures. It features high product gas concentration and fast separation efficiency, and is mainly applied in carbon capture projects such as natural gas processing and syngas purification. In addition to carbon capture technology itself, the resource utilization of carbon dioxide is also an important component of green chemical engineering technology. Carbon dioxide can be chemically synthesized into high-value-added chemicals such as methanol and ethanol, providing resources for the chemical industry. In addition, through Fischer-Tropsch synthesis technology, carbon dioxide can also be converted into synthetic fuels, enhancing its application value in environmental protection projects. In the field of building materials manufacturing, carbon dioxide is injected into cement or concrete to form carbonated products, enhancing the performance of building materials. The development of green synthesis processes has effectively reduced the generation of by-products and improved product purity [7].

3.4. The utilization of carbon dioxide in agriculture and biology and the significance of carbon capture and utilization technologies

Carbon dioxide also has extensive applications in agriculture and biology. As a greenhouse gas, carbon dioxide can effectively promote plant growth. In addition, by utilizing microorganisms or algae, carbon dioxide can be converted into biofuels or biochemicals, further expanding the application scope of environmentally friendly materials. Carbon capture and utilization technology is an important means to achieve the goal of carbon neutrality. Through continuous innovation in green chemical technology, the efficiency of carbon capture projects can be effectively enhanced, energy consumption and costs can be reduced, and the resource recovery and utilization of carbon dioxide can be achieved at the same time. This is of great significance for promoting the preparation of new energy and addressing climate change.

4. Conclusion

This thesis mainly explores the application and innovation of green chemical engineering technology in the preparation of new energy, with a focus on analyzing the key roles of hydrogen energy preparation and carbon capture technology in promoting sustainable development. Research has found that green chemical engineering technologies have demonstrated significant advantages in the field of new energy. Hydrogen production technologies such as electrolysis of water for hydrogen production, as well as carbon capture technologies like chemical absorption methods, have achieved remarkable results in reducing carbon emissions and improving energy utilization efficiency. Through technological innovations such as catalyst improvement and membrane material optimization, the efficiency and economy of these technologies have been significantly enhanced, providing strong support for achieving the carbon neutrality goal.

However, this paper has not delved deeply into the long-term environmental impact of green chemical engineering technologies. Future research can further analyze the environmental footprint of these technologies throughout their entire life cycle to comprehensively assess their sustainability. Furthermore, this thesis did not adopt the field investigation method to analyze the problems in

practical applications. Subsequent research can incorporate field investigations to gain a more comprehensive understanding of the actual effects and challenges faced by the technology.

Looking ahead, research can focus on further optimizing green chemical engineering technologies, such as developing more efficient catalysts and more economical membrane materials. Explore new green chemical engineering technologies, such as the development and application of bio-based materials; Research the integration of green chemical engineering technology with other emerging technologies (such as artificial intelligence and big data) to enhance the intelligent level of energy management; Conduct an in-depth analysis of the application effects of green chemical technology in different regions and industries to provide more specific guidance for policy-making and industrial development. These research directions will help promote the continuous progress of green chemical engineering technologies and contribute to the sustainable development of the new energy sector.

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