CHEMICAL ENGINEERING TRANSACTIONS
VOL. 122, 2025
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Jeng Shiun Lim, Bohong Wang, Guo Ren Mong, Petar S. Varbanov

ISBN 979-12-81206-23-6; **ISSN** 2283-9216
DOI: 10.3303/CET25122025

Patent Status of Alkaline Water Electrolysis: a Hydrogen Production Technology

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This study sorted out the development trend of patents for hydrogen production by alkaline water electrolysis, including application trends, competitive landscape, research and development institutions, technical composition, and other relevant information. It provides valuable guidance for technical R&D personnel to identify innovation directions more accurately and helps managers and decision-makers understand technology evolution trends, so as to balance efficiency gains with innovative breakthroughs and maximize technological value. The study discovered that the development of alkaline electrolysis hydrogen production technology has been active, and Chinese enterprises have participated in the layout of patents in recent years. China has formed a competitive advantage in the field of alkaline electrolysis hydrogen production technology.

1. Introduction

As one of the breakthroughs in the future energy revolution, the development and utilization of hydrogen energy will inevitably bring about major changes in the energy structure. To better cope with climate change, hydrogen energy is a crucial tool. Here, hydrogen, as an energy carrier, presents an alternative pathway beyond its traditional role as a chemical feedstock (Arras et al., 2024). The hydrogen energy industry is currently characterized by strong momentum for technological innovation, robust policy support, vast market potential, promising development prospects, and intensifying global competition. The entire hydrogen energy industry chain continues to evolve, with technologies in the hydrogen production sector - which forms the upstream segment - advancing rapidly. The technical routes can be divided into fossil energy hydrogen production, industrial by-product hydrogen production, biomass hydrogen production, water decomposition hydrogen production according to different energy sources (Du et al., 2025). Existing studies have divided hydrogen production from water electrolysis into alkaline water electrolysis (AWE), proton exchange membrane water electrolysis (PEM), solid polymer anion exchange membrane water electrolysis (AEM) , and solid oxide water electrolysis (SOEC) (Yu et al., 2021). Alkaline water electrolysis is one of the most established technologies for green hydrogen production (Dias et al., 2025). Among the four routes for hydrogen production by electrolysis of water, technology areas of the AWE has the largest number of patents (Yang et al., 2023). And it has been commercialized with the high technology readiness level. Still, problems such as low current density have limited its hydrogen production efficiency to a certain extent. At the same time, it faces important challenges such as the high cost of renewable electricity and compatibility with renewable energy (Acharya, 2022).

Alkaline water electrolysis for hydrogen production uses direct current to decompose water molecules in an alkaline electrolyte solution, where water on the cathode side gains electrons to undergo hydrogen evolution reduction reaction, generating hydrogen and hydroxide ions. Driven by the electric field and concentration gradient of hydroxide ions, the hydroxide ions pass through the physical diaphragm, lose electrons on the anode side, and undergo oxygen evolution oxidation reaction, producing oxygen and water. The core structures of alkaline water electrolysis include the electrolyzer and the system. Studies have analyzed the patent status of different hydrogen production technologies. Most of the direct seawater electrolysis' patents dedicated to the development of new electrolytic systems (de Moura et al., 2024). There has been a significant increase in the growth of electrolyser patents since 2018 (Acharya, 2023). What is the current competitive landscape of alkaline water electrolysis hydrogen production technology? Which innovators have played a key role in the

Paper Received: 21 August 2025; Revised: 9 October 2025; Accepted: 28 November 2025
Please cite this article as: Wang C., Guo Y., Ao J., Du W., Cai R., 2025, Patent Status of Alkaline Water Electrolysis: A Hydrogen Production Technology, Chemical Engineering Transactions, 122, 145-150 DOI:10.3303/CET25122025

development? What are the hot spots of technology research? This study aims to analyze the above issues from the patent perspective, provide valuable information for decision-makers or managers in different countries and regions, and promote the development of alkaline water electrolysis hydrogen production technology.

2. Method and data

This study investigated the status quo of alkaline water electrolysis hydrogen production technology and classified electrolyzers according to their structures, such as diaphragms, gaskets, plates, electrodes, etc., to lay a solid foundation for in-depth mining of patent information. In terms of retrieval, this study selected keywords such as "alkaline solution" and "electrolysis", combined with international patent classification, and constructed a patent search strategy. This study mainly used statistical analysis methods to find out the regional competition pattern, main Research and Development institutions, technical composition, and patent protection types of alkaline water electrolysis hydrogen production technology.

This paper use the RCESIPat platform's patent data. The platform is an independent platform that provides 190 million patent data information from more than 120 countries and regions, supported by the Technology and Innovation Support Center (TISC) of the Dalian Institute of Chemical Physics, Chinese Academy of Sciences (Ao et al., 2025).

On June 30, 2024, 1,462 patent families of alkaline water electrolysis hydrogen production technology were retrieved on the RCESIPat platform. It should be noted that the publication of a patent takes a long time, such as invention patents usually being published 18 months from the date of application. So the data after 2023 is less than the actual number, and the chart data may show a downward trend.

3. The global landscape of hydrogen production

3.1 Patent application trends

The current status quo of patent application trends is presented, as depicted in Figure 1. At the end of June 2024, the number of global patent families for alkaline water electrolysis hydrogen production reached 1,462. The alkaline water electrolysis hydrogen production technology has developed steadily. Before 2015, the number of patent families per year was less than 30. However, the number of patent families has surged in recent years, reaching 300 in 2022, showing a sharp upward trend. This is related to the expansion of the market scale of hydrogen production by water electrolysis. Electrolysis capacity for dedicated hydrogen production has been growing in the past few years, reaching an installed capacity of 1.4 GW (the capacity of alkaline is 840 MW) at the end of 2023, almost double the one at the end of 2022 (IEA., 2025). It can be expected that patents for alkaline water electrolysis hydrogen production will continue to grow in the future.

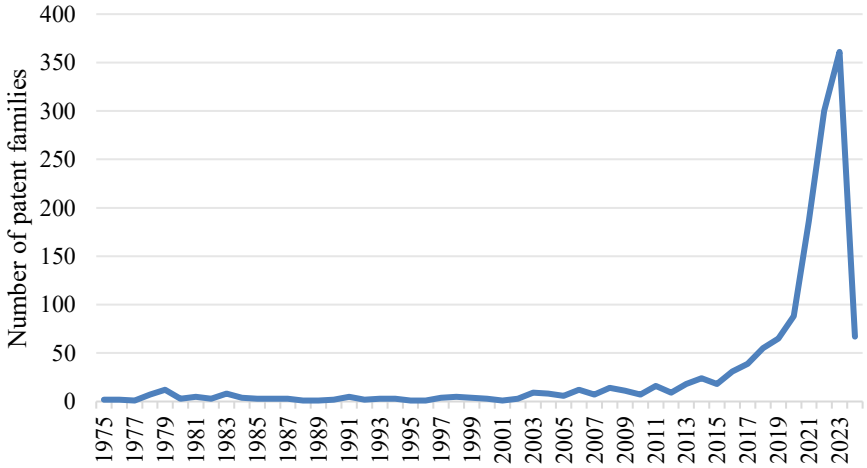

Figure 1: Patent application trend of hydrogen production by alkaline water electrolysis

Figure 2 shows the trend of patent application proportions among China, the United States, Japan, Germany, and South Korea. The United States, Japan, and Germany developed alkaline water electrolysis hydrogen production technology earlier, especially the United States, which has a large proportion of patent applications in the past fifty years. South Korea started later and has fewer patent applications. In the past twenty years, the proportion of applications in China's alkaline water electrolysis to produce hydrogen has increased gradually

and has maintained the top position in the past decade.

China continues to promote the combined use of water electrolysis for hydrogen production and renewable energy. According to statistics from the IEA, China leads in new installations and also in scale of new projects: two of them, in the hundreds of MW scale, accounted for more than half of the capacity added globally in 2023.

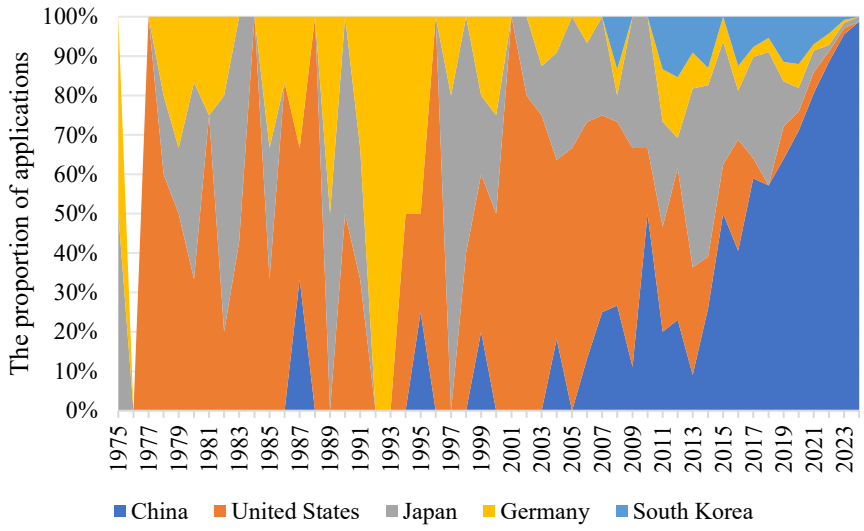

Figure 2: Patent application trends of major source countries

3.2 Research and Development institutions

In order to identify the primary sources of innovation in alkaline water electrolysis hydrogen production technology, this section analyzes the first applicants of related patents, as illustrated in Figure 3. Major researchand development institutions in China - including companies, universities, and research institutes - show relatively strong performance. Notably, among the top 10 first applicants for patents in this field, only one is a Japanese company.

The top 10 applicants demonstrate a forward-looking approach in developing alkaline water electrolysis hydrogen production technology and have shown strong strategic initiatives in commercialization and international cooperation. They are expected to expand their commercial activities related to alkaline water electrolyzers in 2025.

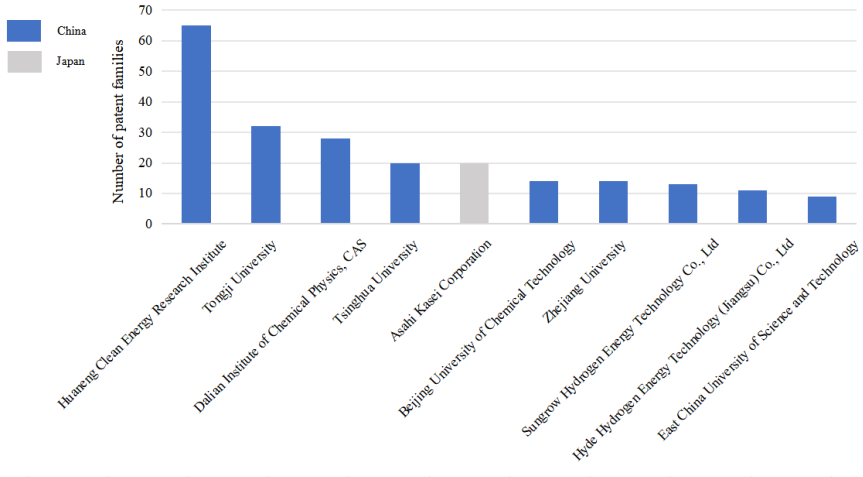

Figure 3: Top 10 first applicants for alkaline water electrolysis hydrogen production patents

3.3 Maintenance time of Patents

The maintenance time of valid patents for alkaline water electrolysis hydrogen production technology is shown in Figure 4. Maintenance time refers to the period of a valid patent from the date of application to the present.

Patents with longer maintenance time have a higher technical level and economic value to a certain extent. In terms of the marketization process, alkaline water electrolysis, as the most mature electrolysis technology, occupies a dominant position, especially in the application of some large-scale projects (Yu et al., 2021). 11 valid patents have been maintained for more than 16 years. The number of patents on alkaline water electrolysis hydrogen production has increased sharply in recent years. Most valid patents are maintained for 1-5 years, nearly 400.

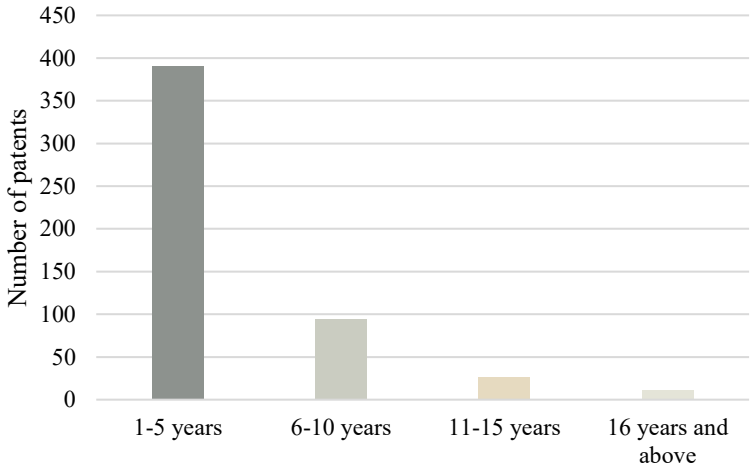

Figure 4: Patent maintenance time for hydrogen production by alkaline water electrolysis

3.4 The composition of technology

Figure 5 presents the composition of alkaline water electrolysis hydrogen production technology. Patents related to the systems account for 35%, and device patents account for 24%. The electrolyzer is the key place for the alkaline water electrolysis reaction. Water is decomposed into hydrogen and oxygen in the electrolyzer (Li et al., 2022).

The majority of patents related to alkaline water electrolysis hydrogen production electrolyzers focus on electrodes and diaphragms, which account for the largest proportion. This reflects that the research and development breakthroughs in electrode and diaphragm technologies are a key driver in advancing alkaline water electrolysis technology to some extent.

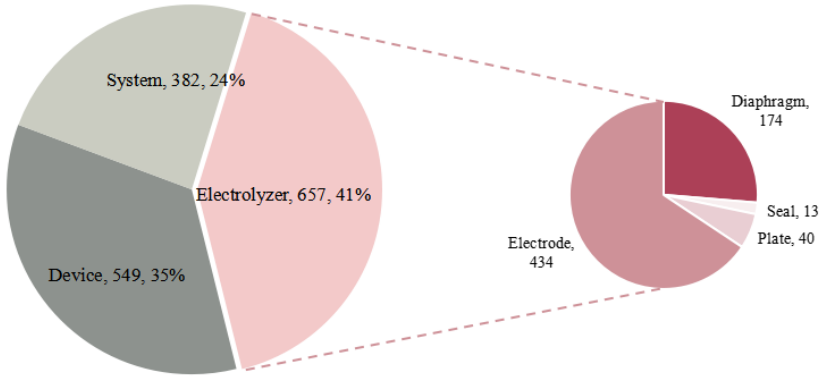

Figure 5: Composition of Alkaline water electrolysis hydrogen production technology

3.5 Types of protection

Figure 6 presents the different types of protection for patent technologies (such as methods, products) which reflect the multidimensional characteristics of technological innovation and the strategic layout of patent protection. The patent protection types for hydrogen production from alkaline water electrolysis are mainly preparation processes or methods, accounting for more than 50 %, while technical protection in the product part

accounts for a quarter, and the use accounts for the lowest proportion, at 13 %. Alkaline water electrolysis hydrogen production technology needs to combine different types of patent protection to further expand the commercial scale.

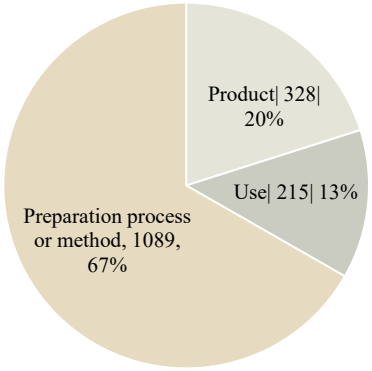

Figure 6: Patent protection types for hydrogen production by alkaline water electrolysis(If a patent belongs to two or more protection types, we count them repeatedly)

3.6 Patent operation status

The patent operation status quo of alkaline water electrolysis hydrogen production is shown in Figure 7. The number of transferred patents is the largest, reaching 332. The number of litigated patents exceeds 40. However the numbers of patented licenses and pledges for alkaline water electrolysis hydrogen production are low. The possible reason is that universities and research institutions lack the ability to transform achievements. Enterprises with the ability to implement prefer direct “buyout”.

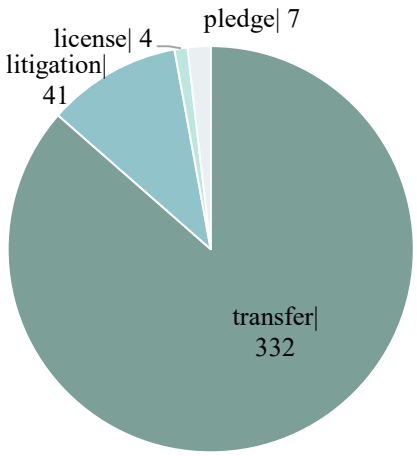

Figure 7: Patent operation status

4. Discussion

With the continuous advancement of technology, the newly proposed integrated CPV-AW electrolyzer system has achieved a solar hydrogen production efficiency of up to 29.1 % at high current density (Zhang et al., 2025). Meanwhile, researchers are actively exploring improments in materials, membranes, and catalysts to improve the efficiency and durability of alkaline water electrolysis hydrogen production systems (Emam et al., 2024). Patent applications related to alkaline water electrolysis hydrogen production are expected to keep lasting growth, preparing for large-scale, multi-scence applications. Countries and different regions should pay attention

to the research and development of alkaline water electrolysis hydrogen production technology to improve the operational efficiency and durability of electrolyzers continuously.

5. Conclusions

Studying the development trends of patents for hydrogen production by alkaline water electrolysis has multiple strategic significance. It is not only linked to the direction of technological breakthroughs but also directly affects the competitive landscape of the industry. The development of alkaline water electrolysis hydrogen production technology has taken a long time. The United States, Japan, Germany have carried out research and development in this field earlier. The number of patent families was stable in the early stage, and has surged in recent years, reaching 300 in 2022. In the past two decades, China's share of such patent families has risen steadily and ranked first in the past decade. From the perspective of the main R&D entities, Chinese enterprises, universities, and research institutes are key players. In terms of specific technical composition, electrolyzers patents in this field are primarily concentrated on electrodes and diaphragms. Further more, most patents are related to preparation methods, accounting for over 50 % of the total. The number of transferred patents is the largest, while the quantities of licensed and pledged patents are relatively small. For a core technological innovation, it is necessary for countries and different regions to simultaneously lay out different types of patents such as product patents, method patents, and use patents, so as to build a more comprehensive and harder-to-circumvent protection network. Competitors need to bypass all types of patents at the same time to enter the market, which greatly increases the difficulty and cost.

Acknowledgments

The authors would like to thank the financial support provided by the China National Intellectual Property Administration (FX202407).

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