Analysis of the Hydrogen Energy Industry's Development Trends and Economic Outlook

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Abstract

Hydrogen has several advantageous qualities, including being carbon-free, highly efficient, and easily storable. It can be derived from diverse clean sources and promotes low carbon emissions and ease of storage. As a result, hydrogen holds significant potential as a key element in achieving collaborative optimization within energy networks. It plays a crucial role in integrating power, heating, fuel, and transportation grids, garnering considerable attention from leading nations. Hydrogen energy is an important way to expand the utilization of electric energy and promote energy interconnection. As a flexible and efficient primary energy, hydrogen energy can be used in the energy consumption side through the use of electrolyzers and fuel cells, promote the development of distributed energy and improve the terminal energy efficiency. In recent years, the development of hydrogen energy industry in our country has been accelerated, and the technology and economic level have been improved. In this paper, we analyze the policy background, technological status, and development trends of the hydrogen energy industry. Additionally, we establish an economic analysis model for hydrogen storage and calculate the economics of hydrogen storage within the peak-valley price spread arbitrage business model.

Keywords

hydrogen energy, economic analysis, development trend

1. Introduction

Developed countries in Europe and America have placed significant emphasis on and provide strong backing for the advancement of the hydrogen energy sector, considering it a crucial focal poin**t for** energy innovation and the revival of industries. The hydrogen energy sector has been of significant importance to the United States, as evidenced by its substantial financial backing of USD 1.7 billion since 2008, aimed at bolstering hydrogen research, development, and widespread adoption. During the Trump administration, hydrogen and fuel cells were given a prominent position as a key energy strategy for the nation. The **EU** considers hydrogen as a pivotal element in ensuring energy security and driving energy transformation. To achieve these goals, the EU has taken various steps, such as establishing the Fuel Cells and Hydrogen Joint Undertaking and increasing investments to support hydrogen and fuel cell research, development, and adoption. The EU has introduced the EU Hydrogen Strategy, which aims to achieve climate neutrality by 2050. This strategy involves reducing the cost of renewable energy, scaling up hydrogen production from renewable sources, and utilizing hydrogen in sectors that are challenging to decarbonize.To support this ambitious plan, the EU proposes to boost the investment budget, with an estimated total investment of over EUR 450 billion. The EU has also set up mechanisms to facilitate investment, including the creation of the European Clean Hydrogen Alliance, coordinating the establishment of the hydrogen supply chain, continuing to back green transformation and renewable energy development, and promoting the coordinated growth of energy and transportation infrastructure.By implementing this strategy, the EU envisions triggering a new wave of clean energy investment centered around hydrogen, leading to job creation and fostering economic recovery in the post-pandemic era. **Germany** has also joined the effort by releasing its National Hydrogen Strategy and has committed to invest EUR 9 billion in hydrogen development by 2030. A notable portion of Germany's domestic hydrogen market relies on hydrogen produced through renewable energy via water electrolysis, and Germany has been actively exporting hydrogen technology worldwide. Spain is also actively soliciting public opinion on its Renewable Hydrogen Roadmap, aiming to install approximately 4 GW of electrolyzers by 2030, contributing to 10% of the EU's target, and emphasizing the use of renewable energy for hydrogen production[1-2].The **Japanese** government has put forward a vision for creating a "hydrogen society" as a solution to tackle resource scarcity. At present, Japan holds the highest number of patents in the hydrogen technology domain and has successfully implemented widespread adoption of fuel cell vehicles and household CHP systems on a large scale. In 2018, the **South Korean** government identified the hydrogen energy sector as one of its three strategic investment areas. The following year, they unveiled the Hydrogen Economy Roadmap, which outlined their ambition to embrace a hydrogen-based society by 2030. Recently, in June of this year, they formed the Overseas Business Group of Green Hydrogen, with the primary objective of exploring and establishing specific projects for the international hydrogen fuel supply chain.South Korean Prime Minister, Chung Sye-kyun, put forward a proposal to designate Saemangeum as the central hub for developing South Korean green hydrogen and positioning the country as a pivotal player in the global "hydrogen transfer station" industry.

The hydrogen energy sector has emerged as a significant component of China's energy strategy framework, with a progressively defined policy direction and industry focus. It is anticipated that a comprehensive national development plan for the hydrogen energy industry will be soon unveiled.From 2012 onwards, hydrogen has consistently appeared in national industrial and technological development strategies. Notably, since 2020, China has significantly emphasized its hydrogen energy industry policies, leading to the extensive implementation of relevant plans across different regions. Table 1 presents an overview of the industrial development policies. In 2019, the government work report of the State Council included the hydrogen fuel cell industry for the first time, leading to an accelerated development of the hydrogen energy sector in various regions. Several provinces, such as Shandong, Hebei, Zhejiang, and Guangdong, responded by issuing their own local hydrogen energy industry development plans, resulting in the establishment of five hydrogen development regions known as "East, West, North, South, and Center." Subsequently, 10 provinces, including Guangdong and Shanxi, integrated hydrogen development into their 2020 local government work reports.In May 2020, the National People's Congress of the People's Republic of China approved the *Report on the Implementation of the 2019 Plan for National Economic and Social Development* and on the 2020 Draft Plan for National Economic and Social Development. This approval emphasized the need to "formulate a national strategic plan for the development of the hydrogen energy industry." In June 2020, the National Energy Administration further reinforced this direction by issuing the "2020 Energy Work Guidance," which explicitly called for the formulation and implementation of a comprehensive hydrogen energy industry development plan[2-3].

2. Development status and trend of China's hydrogen energy industry

The hydrogen energy industry includes links such as hydrogen production, hydrogen storage and transportation, and hydrogen use, as shown in the figure below.

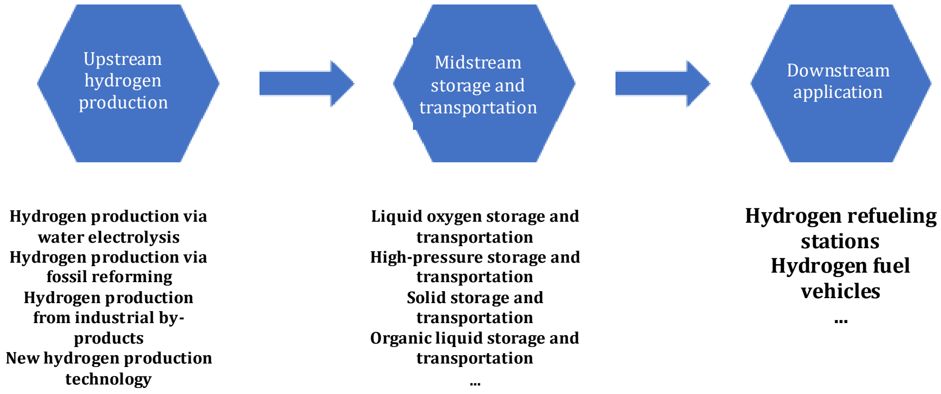

Figure 1 Hydrogen energy industry

2.1. Hydrogen production

Hydrogen production in China is mainly based on fossil energy. Hydrogen production via water electrolysis is a research and application hotspot. There are large gaps between China and foreign countries in terms of proton exchange membrane (PEM) water electrolysis and other technologies.

Hydrogen can be produced through two main methods: conventional means involving fossil energy, and water electrolysis. Within conventional hydrogen production from fossil energy, there are two primary routes: hydrogen production via fossil energy reforming using coal and natural gas, and hydrogen production from industrial by-product gases like coke oven gas, chlor-alkali tail gas, and propane dehydrogenation. In 2018, the global hydrogen output exceeded 70 million tons, with conventional hydrogen production from fossil energy accounting for 96%, while hydrogen production via water electrolysis only constituted 4%.The cost of hydrogen production varies depending on the method used. Water electrolysis, for instance, requires approximately 4 to 5 kWh/m3 of hydrogen in terms of unit energy consumption. The cost of hydrogen production is significantly influenced by the tariff, representing more than 70% of the total cost. For instance, in China's domestic market, the current cost of hydrogen derived from electricity is around RMB 30 to 40/kg,[1] which is notably higher compared to the cost of hydrogen from coal[4].

Water electrolysis for hydrogen production is considered a promising future direction, though there exists a noticeable disparity in technical advancement when compared to foreign countries. The process of hydrogen production via water electrolysis can be primarily classified into three categories: alkaline water electrolysis, PEM water electrolysis, and solid oxide water electrolysis. Table 1 presents a comparison of these three technology roadmaps.Alkaline water electrolysis has reached a commercially mature stage both in China and abroad, boasting relatively lower costs. On the other hand, PEM water electrolysis is currently a focal point of research and application due to its high operational flexibility and reactivity. However, there is a significant technology gap between China and foreign nations in this area. As for solid oxide water electrolysis, it shows promise in enhancing hydrogen production efficiency but is currently confined to laboratory tests and small-scale demonstrations.For instance, proton exchange membrane water electrolysis technology, which holds excellent development prospects, has seen advancements by companies like American Proton Onsite, who have successfully developed megawatt units for commercial hydrogen production. Unfortunately, China lags in this technology, as exemplified by The 718th Research Institute of CSSC and Dalian Institute of Chemical Physics, whose developed units are only in the tens of kilowatts range and are still undergoing laboratory testing[5].

Table 1 Comparison of technical indicators for hydrogen production via water electrolysis

Characteristic	Alkaline water electrolysis	PEM water electrolysis	Solid oxide water electrolysis
Energy efficiency	60%~75%	70%~90%	85%~90%
Operating temperature (°C)	70~90	70~80	700~1000
Start/stop speed	Relatively fast	Fast	Slow
Dynamic response capability	Relatively strong	Strong	-
Power quality requirement	Stable power supply	Stable or fluctuating	Stable power supply
System O&M	Corrosive liquid presence, complex O&M in the later stage, and high cost	Corrosive liquid presence, simple O&M in the later stage, and low cost	Technology research dominated currently and no O&M requirement
Electrolyzer life	12,000 h, achievable	10,000 h, achieved	-
Electrolyzer cost (USD/kW)	400~600	About 2,000	1,000~1,500
Safety	Relatively poor	Relatively good	Relatively poor
Footprint area	Relatively large	Small	Unknown
Feature	Mature technology, large-scale industrial applications, and low cost	Relatively good adaptability to renewable energy, no pollution, and high cost (PEM replacement and precious metal electrodes)	Replacement of part of electrical energy by thermal energy, high conversion efficiency, limited material selection due to high temperatures, and no industrialization
Representative foreign enterprises	Mcphy (France), Teledyne (United States), Nel (Norway)	Proton (United States), Hydrogenics (Canada)	-
Representative Chinese enterprises	Suzhou Jing Li Hydrogen Equipment Co., Ltd., Tianjin mainland Hydrogen Equipment Co., Ltd., and The 718th Research Institute of CSSC	The 718th Research Institute of CSSC, Beijing SinoHy Energy Co., Ltd., Dalian Institute of Chemical Physics, Angstrom, and The 507th Institute (Astronaut Center of China)	-

In the coming years, the primary focus for hydrogen production is expected to remain on utilizing fossil energy sources, while the development direction for the medium to long term will be centered around hydrogen production through water electrolysis, particularly using renewable energy sources. Currently, the cost of producing hydrogen from electricity remains relatively high, leading to hydrogen production being predominantly reliant on fossil energy sources. However, this approach results in a significant by-product of carbon dioxide, which contradicts the growing trend toward low-carbon and environmentally friendly practices.

As water electrolysis technologies, such as PEM water electrolysis, become more commercially viable, they are likely to dominate hydrogen production in the future. This shift will be driven by the need for more sustainable and eco-friendly methods. Furthermore, to address carbon emissions stemming from hydrogen production [3] through fossil energy power generation, there will be a gradual increase in the proportion of renewable energy used for hydrogen production.

2.2. Hydrogen storage and transportation

China's hydrogen storage and transportation technologies are limited and outdated, which hinders their ability to facilitate the use of hydrogen in power-to-gas applications, long-term energy storage, transportation, and other related areas.

Three primary methods of hydrogen storage exist: gas hydrogen storage, liquid hydrogen storage, and hydrogen storage with specialized materials. Table 2 outlines the technical distinctions among these methods. Presently, high-pressure gas hydrogen storage stands as the most well-established and cost-effective technology, extensively employed both domestically and internationally. In China, 20 MPa hydrogen storage tanks are prevalent, whereas overseas, 50 MPa and 100 MPa hydrogen storage cylinders have been developed.

Liquid hydrogen storage offers advantages such as high density, significant storage capacity, enhanced safety, but it comes with a higher cost. In foreign nations, approximately 70% of hydrogen transportation relies on liquid hydrogen, and safety concerns during transportation have been extensively studied. However, in China, its utilization is currently confined to the aerospace sector, with limited applications in civilian domains. Furthermore, there is a notable absence of technical standards and policy specifications for liquid hydrogen in the country[6-8].

On the other hand, hydrogen storage materials, due to their technical complexity and other factors, remain in the experimental phase, both in China and abroad, with laboratory testing being the primary focus.

Table 2 Status of hydrogen storage technologies and comparison of applications in China and abroad

Comparison item	High-pressure gas hydrogen	Liquid hydrogen storage	Solid hydrogen storage
Hydrogen storage cost	Low	High	Medium
Application status	70 MPa IV cylinders represent the mainstream technology for onboard hydrogen storage abroad; 35 MPa III cylinders represent the mainstream technology for onboard hydrogen storage in China	Has been widely applied abroad, but has only been successfully applied in aerospace engineering in China	Has been widely applied for large-scale hydrogen storage abroad; solid hydrogen storage has been demonstrated and applied in distributed power generation in China.
Mass hydrogen storage density	< 5.7wt%	5.1~7.4wt%	4.5~18.5wt%
Safety	Relatively poor	Relatively poor	Safety

Hydrogen is primarily conveyed through three methods, namely a hydrogen trailer for gaseous form, a tanker for liquid hydrogen, and a transmission pipeline designed for hydrogen transportation. The distinctions in their respective technical aspects are presented in Table 3. The gas hydrogen trailer, a well-established and crucial means of short-distance transportation, utilizes advanced technology. Internationally, 45 MPa high-pressure hydrogen cylinder long-tube trailers are employed for hydrogen transport, enabling each vehicle to carry up to 700 kg of hydrogen. Meanwhile, in China, 20 MPa long tube trailers are commonly utilized, allowing for a single-vehicle capacity of 300 kg of hydrogen during transportation. The utilization of liquid hydrogen tankers is well-suited for extensive and high-capacity transportation needs, offering excellent efficiency and cost-effectiveness. The United States and Japan have embraced gas hydrogen tankers as a significant means of transporting hydrogen for refueling stations, whereas China has yet to achieve commercialized liquid hydrogen transportation. A hydrogen transmission pipeline serves as a means to transport hydrogen over extensive distances on a large scale, offering the potential to significantly lower transportation expenses. However, in China, the extent of hydrogen pipeline transportation significantly lags that of more developed nations. The United States and Europe, for instance, have constructed approximately 2,400 km and 1,598 km of hydrogen transmission pipelines, respectively, whereas China has only managed to establish around 100 km of such pipelines. This deficiency in hydrogen storage and transportation technologies directly hampers the diverse growth and widespread adoption of hydrogen in energy storage, transportation, and other critical domains[9-10].

Table 3 Status of hydrogen transportation technologies and comparison of applications in China and abroad

Comparison item	Hydrogen transportation by gas hydrogen trailer	Hydrogen transportation by liquid hydrogen tanker	Pipeline hydrogen transportation
Pressure (MPa)	20	0.6	1~4
Application status	Widely used for the transportation of commercial hydrogen	Widely used abroad and currently only used in aerospace and military fields in China	In a stage of small-scale development aboard and not yet widespread in China
Hydrogen carrying capacity (kg/vehicle)	300~400	7000	--
Volumetric hydrogen storage density (kg/m3)	14.5	64	3.2

In the coming years, the predominant methods for storing and transporting hydrogen will be through flexible gas hydrogen trailers and liquid hydrogen tankers. However, there is a shift anticipated toward more cost-effective pipeline transportation as time progresses. During this transitional period, hydrogen will continue to be primarily stored as a high-pressure gas at approximately 70 MPa, with some support from low-temperature liquid hydrogen, and it shall be transported mainly using vehicles.

Looking further ahead in the medium to long term, the transportation capacity of hydrogen transmission pipelines will improve significantly. This improvement will be facilitated by the establishment of centralized hydrogen production bases and the growth of the consumer market. As a result, pipeline transportation will gradually demonstrate its advantages over other methods. Consequently, in the medium to long term, we can expect hydrogen storage and transportation to transition from reliance on high-pressure gas and liquid hydrogen tanks to a more economical approach through low-cost pipeline transportation[11].

2.3. Hydrogen use

Currently, hydrogen finds its primary utilization within the industrial sector. In 2018, about 48% of the world's hydrogen was employed in petroleum refining, while approximately 43% was utilized in ammonia production. However, with the rapid advancement of fuel cell technology in recent years, there has been an increasing push to explore hydrogen's potential in transportation and power generation domains. In the transportation industry, the utilization of fuel cell vehicles has been swiftly advancing. While these vehicles find their primary use in passenger cars overseas, they are predominantly employed for commercial purposes in China. However, it is evident that China's vehicle research, development, and technological standards are trailing those of developed nations. Regarding fuel cell applications, the global number of fuel cell vehicles rose to 25,210 in 2019, marking a significant year-on-year increase of 12,350 vehicles or 112%. Throughout the same year, international sales of fuel cell vehicles reached 7,578 units, showing a remarkable 90% year-on-year growth. These sales were predominantly concentrated in South Korea, the United States, and Japan, with the majority of the vehicles being passenger cars. Additionally, owing to China's favorable policy support for commercial fuel cell vehicles, the sales of fuel cell vehicles in China in 2019 reached 2,737 units, exhibiting a notable year-on-year increase of 79.2%. Notably, the majority of these sales in China were attributed to commercial vehicles. When it comes to producing fuel cells, the United States, Japan, and South Korea remain at the forefront. Fuel cell vehicles in these countries have achieved a level of performance, reliability, service life, and adaptability to the environment that can be compared to conventional gasoline vehicles. While China's fuel cell vehicle industry is making progress and becoming more mature, there still exists a gap in core materials, component quality, and overall service life when compared to the developed countries. This gap is mainly attributed to limitations in research and development of low platinum and ultra-low platinum catalysts, as well as membrane electrodes.

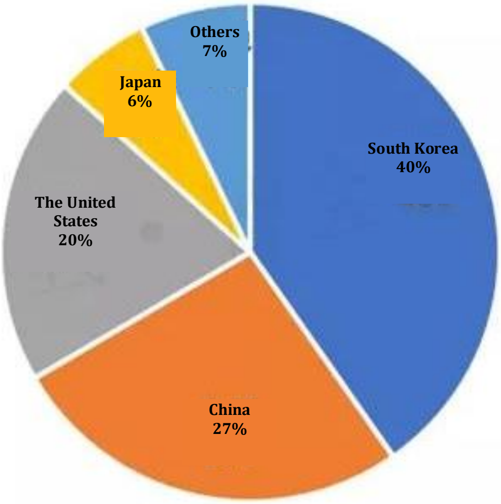

Figure 2 Comparison of global sales data of fuel cell vehicles in 2019

In the realm of power generation, fuel cell power generation primarily thrives in nations like Japan, the United States, and South Korea. However, China lags in technology and suffers from a dearth of pertinent standards and policies, resulting in limited adoption of fuel cell applications in the country. There are two primary fuel cell power generation scenarios: independent power plants and household CHP systems. The current independent power plants are mainly found in the United States, South Korea, and Japan. In China, there is only a single 2

MW fuel cell power generation system located in Yingkou City, Liaoning Province. Household CHP systems, on the other hand, are predominantly utilized in Japan and Germany, with Japan having 274,000 deployed units. Unfortunately, there are no market-oriented products available for this purpose in China.

In Japan, hydrogen is produced through natural gas reforming in household CHP systems. The hydrogen is then fed into fuel cells to generate electricity, and the heat generated during this process is simultaneously utilized for heating and hot water supply. Overall, these systems boast an impressive energy efficiency of up to 90%, resulting in significant cost savings for users, averaging around RMB 60,000 per year for lighting and heating expenses.

In future, fuel cells are expected to find primary application in the transportation sector, initially focusing on commercial vehicles and later extending to passenger vehicles. As we move toward the medium to long term, fuel cells are projected to be extensively adopted in various other forms of non-road transportation, including ships.

At present, fuel cell vehicles face limitations due to factors like underdeveloped supporting industries and significant expenses. Although they lack a competitive edge in the realm of passenger vehicles compared to electric vehicles, they can capitalize on their strengths in extensive range and ample energy storage for advancement in commercial applications, particularly in long-distance transportation and the transport of heavy goods using logistics vehicles and buses.

In the foreseeable future, medium to long term, the utilization of fuel cell vehicles is expected to broaden from commercial to passenger vehicles, driven by advancements in the hydrogen energy industry, technological improvements, and cost reductions. These vehicles will coexist and work in synergy with electric vehicles for an extended period. As per the Investigation Report on the Future Development Trend of Hydrogen by the Hydrogen Council, it is projected that by 2030, there will be an estimated 10 to 15 million fuel cell passenger vehicles globally. Furthermore, there are also plans to explore the application of fuel cells in other modes of transportation like ships and airplanes.

3. Cost-benefit analysis for hydrogen energy storage

3.1. Calculation of hydrogen energy cost per kWh with the method for calculating tariff during the operating period

The approach to determine the tariff throughout the operational phase relies on a thorough evaluation of cost fluctuations and loan requirements for each year throughout the economic lifespan of the power project. Currently, the process involves determining the tariff by evaluating the yearly cash flow generated by the power project. The tariff is set in a way that ensures the net cash flow for each year throughout the project's economic lifespan is sufficient to achieve the financial IRR computed based on the project's registered capital. This approach remains in use to date.

$$P = \frac{I_0 + V_R(1+r)^{-n} + \sum_{n=0}^{N}(C_n - B_n)(1+r)^{-n}}{\sum_{n=0}^{N} A_n (1+r)^{-n}}$$

Where, I_0 is the initial investment; V_R is the system's residual value; C_n is the annual cash inflow; B_n is the annual cash outflow.

3.2. Cost-benefit analysis for hydrogen energy storage

Electricity-derived hydrogen and hydrogen storage have the potential to serve as adaptable power sources and long-term energy storage solutions. These resources can significantly contribute to system regulation during the developmental phase, particularly when the system relies heavily on renewable energy sources. Regarding hydrogen derived from electricity, it serves as a controllable load and boasts exceptional regulation capabilities, making it ideal for both system peak shaving and frequency regulation. To illustrate, the PEM equipment used for hydrogen from electricity can achieve peak shaving depths between 100% to 160%, a ramp rate of 100% per second, and a swift cold start time of just 5 minutes. Additionally, hydrogen proves to be well-suited for large-scale, long-term energy storage, thereby bolstering regulation capacity in future scenarios characterized by a substantial share of renewable energy sources. The scale of hydrogen energy storage can range from KW to GW, and with the utilization of cavern hydrogen storage, the storage capacity can soar to 100 GWh, with storage periods spanning from several hours to several months. This enables accomplishing seasonal energy storage and effective peak shaving.

Up until now, the viability of hydrogen energy storage has primarily hinged on two factors: the cost of hydrogen energy storage itself and the potential for energy arbitrage. To assess the cost-effectiveness, it becomes necessary to examine the kWh cost throughout the entire lifespan of hydrogen energy storage and compare it to established energy storage methods like commercially available pumped storage and the fast-developing electrochemical energy storage. On the other hand, evaluating energy arbitrage involves analyzing whether the existing differences in peak and off-peak tariffs can effectively translate into monetary value for stored energy.

In the present economic climate of hydrogen energy storage, and operating under the unitary system tariff mode, a point of cost neutrality can be reached when the difference between peak and valley tariffs amounts to RMB 0.9/kWh. Currently, in Zhejiang, Hubei, and Chongqing, hydrogen energy storage proves to be economically viable with an IRR surpassing 6%. Moreover, under the two-part price model, all 18 provinces can generate profits from this venture. However, it's important to note that the specific peak and valley prices required to achieve cost neutrality vary among provinces, owing to differing demands and tariff structures.

4. Conclusion

It is essential to consistently monitor the progress of hydrogen technologies, concentrating on researching and developing practices within the global hydrogen energy sector. Particular emphasis should be placed on technologies associated with Energy Internet advancements, such as electricity-based hydrogen production, hydrogen energy storage, and fuel cells. Furthermore, a thorough investigation into macro strategic aspects, including strategic policies, technology roadmap, business models, and their corresponding effects, is warranted.

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References

[1] Rupali N,Sumita S,Leo S H, et al. Recent developments in state-of-the-art hydrogen energy technologies – Review of hydrogen storage materials[J]. Solar Compass,2023,5.

[2]. Results of Joint Research into Hydrogen Energy Solutions Supported by the Toyota Mobility Foundation were Published in the International Journal of Hydrogen Energy[J]. M2 Presswire,2023.

[3] Faruk O N,Mahmudul M H,Nezih P. A Global Review of the Hydrogen Energy Eco-System[J]. Energies,2023,16(3).

[4] Zhenjun L,Qing Z,Weiguo Z, et al. Economic operation strategy of integrated hydrogen energy system considering the uncertainty of PV power output[J]. Energy Reports,2023,9(S3).

[5] A. A A,I. A R,V. V K, et al. Technological and Economic Barriers to Hydrogen Energy Growth[J]. Herald of the Russian Academy of Sciences,2023,92(6).

[6] Anonymous. China's Mintal Hydrogen Energy selects Topsoe technology for green ammonia plant[J]. Chemical Week,2023,185(3).

[7] Dongshi S,Di G,Danlan X. Using Multicriteria Decision Making to Evaluate the Risk of Hydrogen Energy Storage and Transportation in Cities[J]. Sustainability,2023,15(2).

[8] Alberto B. Supply of abundant and low-cost total primary energy to a growing world needs nuclear energy and hydrogen energy storage[J]. International Journal of Hydrogen Energy,2023,48(5).

[9] Ghazala A,Suleman S,Rida W, et al. Significance of hydrogen energy to control the environmental gasses in light of COP26: A case of European Countries[J]. Resources Policy,2023,80.

[10] Yongyan X,Yuan D,Wei L, et al. Research progress of hydrogen energy and metal hydrogen storage materials[J]. Sustainable Energy Technologies and Assessments,2023,55.

[11] Fanyue Q,Weijun G,Dan Y, et al. An Analysis of the Potential of Hydrogen Energy Technology on Demand Side Based on a Carbon Tax: A Case Study in Japan[J]. Energies,2022,16(1).