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Political sciences

New Trends and Prospects of Hydrogen Energy in the World and in Kazakhstan

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Abstract. The article explores the trends in the development of hydrogen energy both in the world in general and in Kazakhstan in particular. The author considers the growing interest in hydrogen energy in the context of the need to reduce greenhouse gas emissions and search for alternative energy sources. The article analyzes key international and national initiatives in the field of hydrogen energy, including the development of technologies for the production, storage and use of hydrogen. Particular attention is paid to the role of Kazakhstan in the development of hydrogen energy and its cooperation with other countries, especially with the EU and Japan, which has significant experience in this area. The author draws conclusions about the prospects for hydrogen energy.

Keywords: energy transformation, hydrogen energy, economic efficiency, international actors, hydrogen economy

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Introduction

In recent years, hydrogen energy has become one of the key areas in the field of alternative energy sources. Hydrogen is a clean and sustainable source of energy, producing no greenhouse gas emissions. This makes it particularly attractive to countries seeking to reduce their dependence on fossil fuels and reduce their negative impact on the environment.

Interest in hydrogen energy is growing around the world. Many developed countries are actively investing in research and development in this area, developing national

strategies and legislation to promote the development of the hydrogen economy. Hydrogen production from renewable energy sources such as solar and wind power is growing. Electrolysis technologies, which produce hydrogen from water using electricity, are becoming increasingly efficient and cost-effective. Demand for hydrogen is growing in a variety of industries, including transportation, chemicals, glass, food processing, oil refining, metallurgy and energy [6:38]. Hydrogen fuel cells are becoming increasingly popular in the automotive industry, used in manufacturing processes and as a source of energy for power grids.

In recent years, the world community has increasingly paid attention to hydrogen energy due to the gradual depletion of traditional fossil fuels and the desire to reduce greenhouse gas emissions. According to the forecast of the International Renewable Energy Agency (IRENA)[1], Hydrogen can be a key element of the future energy system and reduce dependence on fossil resources. The forecast proposes a compelling path to decarbonization across all energy use areas, with electrification and energy efficiency driven by renewables, green hydrogen and sustainable modern bioenergy[2]. It is possible that by 2050 hydrogen energy will account for about 12% of global energy consumption [10:35].

Many countries have already begun to invest in hydrogen energy and develop corresponding national strategies. Japan, Germany, the United States and Australia are actively developing hydrogen technologies and creating infrastructure for the use of hydrogen in vehicles. One of the main reasons for switching to hydrogen is to prevent global warming caused by fossil fuel use [2:217].

In connection with the Russian view on hydrogen energy, its role in the global energy balance and importance for the Russian Federation, let us pay attention to the works of M.G.Borisova [1], G.N.Dolenko [2], A.Konoplyanika [3], Yu.N.Linnik and E.D.Falyakhova [4], E.B.Malykh and V.A.Plotnikova [5], D.K.Chugunova and R.A.Kasyanov [9] and other authors. Among the foreign authors, we note: A.Alsalman [11], P.Atanassov [12], A.Boretti [13], M.Genovese [16], J.Nowotny [17] and others.

This topic is still new for Kazakh researchers. In this regard, the purpose of this article is to consider the main trends in hydrogen energy. The objectives of the study are: 1) to study the world experience in introducing hydrogen energy; 2) describe the achievements, obstacles and general course of development of Kazakhstan in this direction.

Materials and Methods

To achieve the goal – to describe the achievements and course of Kazakhstan in the field of hydrogen energy development – historical, analytical methods and the method of discourse analysis of articles in the media, scientific articles in peer-reviewed Russian, Kazakh and foreign publications, forecast reports, regulations and programs were used development.

Results

Key players in the global hydrogen market. The companies are major players in the global hydrogen market and play an important role in the development and commercialization of hydrogen technologies. Many companies in different countries are actively investing resources and conducting research in the field of hydrogen production, storage, transportation and use. Among the key companies in the global hydrogen market are the following:

Large oil and gas companies such as Shell, Total Energies, BP, and Exxon Mobil are developing hydrogen technologies and investing in infrastructure for the production and use of hydrogen. They are also working on developing hydrogen production projects using renewable energy sources[3].

Electrolyser Manufacturers: companies such as Nel Hydrogen, ITM Power, Siemens Energy, Ballard Power Systems are leading manufacturers of electrolysers, devices that break water into hydrogen and oxygen. They are developing electrolysers of various capacities and technologies[4].

Fuel Cell Manufacturers: companies such as Ballard Power Systems, Plug Power, Hydrogenics, Toyota, Hyundai, develop and manufacture fuel cells that use hydrogen to produce electricity. They specialize in various types of fuel cells, including polymer electrolyte membrane fuel cells (PEMFC), oxide ceramic fuel cells (OCFC), and others.

Automobile Manufacturers: Major automobile companies such as Toyota, Hyundai, BMW, Daimler, Audi are developing and producing hydrogen fuel vehicles (hydrogen fuel cells or combustible cells). They are investing in the development of hydrogen infrastructure and working to create affordable and efficient hydrogen cars.

Manufacturers and suppliers of hydrogen infrastructure: Air Liquide, Linde, Air Products companies provide solutions for storing, transporting and distributing hydrogen. They specialize in the design and construction of fueling stations for hydrogen cars, as well as the development of pipelines and hydrogen storage facilities[5].

1 International Renewable Energy Agency (IRENA) – an intergovernmental international organization founded in 2009 to support the use of all forms of renewable energy sources. IRENA makes it easy to access all the information you need about renewable energy sources, including technical data.

2 Forecast for the transformation of the global energy system. Available from: https://www.irena.org//media/Files/IRENA/Agency/Publication/2021/Jun/IRENA_World_Energy_Transitions_Outlook_Summary_2021_RU.pdf?rev=bbc217fbc6ea48b69a318b6475cc96e4

3 Hydrogen. Available from: https://www.shell.com/energy-and-innovation/new-energies/hydrogen.html Hydrogen & renewable hydrogen. Available from: https://gasmobility.totalenergies.com/gas-fuel-products/hydrogen-renewable-hydrogen Energy Outlook. Available from: https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/hydrogen.html Advancing climate solutions. Available from: https://corporate.exxonmobil.com/what-we-do/delivering-industrial-solutions/advancing-climate-solutions

4 Nel Hydrogen. Available from: https://nelhydrogen.com/ TM Power. Available from: https://www.itm-power.com/ Siemens Energy. Available from: https://www.siemens-energy.com/global/en/innovation/hydrogen.html Ballard Power Systems. Available from: https://www.ballard.com/

5 Air Liquide. Available from: https://www.airliquide.com/hydrogen Linde. Available from: https://www.linde.com/en/what-we-do/hydrogen-energy Air Products. Available from: https://www.airproducts.com/industries/energy/hydrogen-energy

Renewable Hydrogen Companies: with increasing interest in clean sources of hydrogen, companies such as Orsted, Iberdrola, NextEra Energy, Engie are developing and implementing hydrogen production projects using renewable energy sources, including wind and solar power[6].

Transport Companies and Logistics Operators: Transport and logistics companies such as DHL, UPS, Amazon are developing plans and implementing projects to use hydrogen technology in their operations. This could include the use of hydrogen trucks, drones or other means of transport to deliver goods.[7]

Hydrogen fuel production and storage companies for stationary applications: companies such as Bloom Energy, FuelCell Energy, Mitsubishi Power develop and offer hydrogen-based electricity generation systems for stationary applications such as power plants, energy storage and home power systems[8].

The growth of the hydrogen economy requires significant investment, and finance and investment companies play an important role in raising capital and financing projects. Venture capitals, banks and investment funds are actively investing in startups and companies related to hydrogen technologies.

Hydrogen power plants of a car (cylinder with compressed hydrogen+fuel cell+electric motor) at first glance look attractive both in price and in terms of performance characteristics. However, the main incentive for their development is the reduction of greenhouse gas emissions into the atmosphere. The lack of hydrogen infrastructure is one of the main obstacles to the development of hydrogen transport. A solution to the problem may be the use of hydrogen as fuel for an internal combustion engine, or mixtures of fuel with hydrogen.

Creating a wide hydrogen gas station infrastructure at the current level of technology is an extremely expensive task (about $5 billion to cover 10% of US vehicles) and an unresolved technical, economic and safety task [19]. The danger of explosions of an "explosive mixture" in the event of a leak of hydrogen with atmospheric oxygen during the massive use of compressed hydrogen is very high. Safe methods of storing hydrogen are either too expensive or low-tech. However, intensive developments are underway in this direction.

Use of hydrogen fuel cells in air transport

ZeroAvia is working on developing electric aircraft using hydrogen fuel cells [13:6]. They aim to replace traditional aircraft engines so that planes can fly entirely on hydrogen without emitting carbon dioxide or other harmful emissions[9].

6 Orsted. Available from: https://orsted.com/ Iberdrola. Available from: https://www.iberdrola.com/ NextEra Energy. URL: https://www.nexteraenergy.com/ Engie. Available from: https://www.engie.com/

7 DHL. Available from: https://www.dhl.com/global-en/home/our-divisions/ecommerce/innovation/hydrogen-fuel-cell-vehicles.html., UPS. Available from: https://www.ups.com/us/en/services/technology-integration/fuel-cell-technology.page., Amazon. Available from: https://www.aboutamazon.com/sustainability/sustainable-operations/transportation/alternative-fuels

8 Bloom Energy. Available from: https://www.bloomenergy.com/. Fuel Cell Energy. Available from: https://www.fuelcellenergy.com/ Mitsubishi Power. Available from: https://power.mhi.com/

9 ZeroAvia. Available from: https://www.zeroavia.com/

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HES Energy Systems is developing hydrogen power systems for unmanned aerial vehicles. They are creating powerful, compact systems that allow them to fly long distances using hydrogen fuel cells[10].

Major aviation company Airbus is conducting research on the use of hydrogen fuel cells in air transport. They are exploring the possibilities of creating hydrogen aircraft[11].

The National Aeronautics and Space Administration (NASA) are also conducting research into the use of hydrogen fuel cells in air transport. They are exploring the use of hydrogen in drones and developing prototypes to test their functionality and effectiveness[12].

Atomic and hydrogen energy

Nuclear-hydrogen energy has prospects for reducing greenhouse gas emissions[13], sustainable development and diversification of energy sources. Here are some of the prospects for this energy concept.

Low-carbon energy: Using nuclear energy in combination with hydrogen production reduces emissions of greenhouse gases and other pollutants into the atmosphere. Nuclear energy is a low-carbon energy source because its production does not emit significant amounts of carbon dioxide.

Energy independence: the development of nuclear-hydrogen energy can reduce dependence on imported oil and gas. Hydrogen can be produced from water, making it affordable and potentially independent of foreign energy suppliers [8:174].

Renewable source of hydrogen: Hydrogen can be produced from renewable energy sources such as solar and wind energy. This allows the use of nuclear-hydrogen energy as a form of storage and use of renewable energy.

Efficient and high energy density: Hydrogen has a high energy density, meaning it can provide a large amount of energy at a relatively low weight, allowing it to be used in a variety of industries, including transportation and power generation.

Infrastructure development: the development of nuclear-hydrogen energy will require the creation of appropriate infrastructure, including a network of nuclear reactors, water electrolysis systems, hydrogen storage and distribution. This can promote the development of technology and innovation in related industries and create new jobs.

Several important challenges associated with nuclear-hydrogen energy should be noted:

Safety: nuclear power requires strict safety measures to prevent possible accidents and leaks of radioactive materials. Robust control, regulation and safety systems are needed to protect the environment and society.

10 HES Energy Systems. Available from: https://hes.sg/

11 Airbus. URL: https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-zeroemission-concept-aircraft-powered-by-hydrogen.html

12 Space Applications of Hydrogen and Fuel Cells. Available from: https://www.nasa.gov/content/space-applications-of-hydrogen-and-fuel-cells

13 Clean Energy Nuclear Power, 30.09.2020. Available from: https://www.iaea.org/sites/default/files/20-02283r.pdf

Waste management: the production of electricity and hydrogen from nuclear energy produces radioactive waste. These wastes require special treatment to minimize their impact on the environment and human health.

Public opinion: nuclear-hydrogen energy evokes different attitudes in society. Awareness campaigns and discussions need to be conducted to achieve consensus and understanding about the benefits and risks of the technology.

Financing and economic efficiency: the introduction of nuclear-hydrogen energy requires significant investments in the construction and maintenance of nuclear reactors, electrolysis systems and infrastructure. This relates to issues of economic efficiency and competitiveness with other energy sources.

Regulation and international cooperation: the development of nuclear and hydrogen energy requires the establishment of appropriate legal and regulatory frameworks at the national and international level. Coordination and cooperation between countries in the field of nuclear safety and hydrogen use are important aspects for the successful implementation of this concept.

All these aspects are important for the development and implementation of nuclear-hydrogen energy. With joint efforts, scientific and technological advances, and support from governments and society, nuclear-hydrogen energy can become a significant factor in solving the energy and environmental challenges of the future.

Hydrogen energy development programs in the world

In the United States, there are several programs aimed at developing hydrogen energy. Some of them are listed below.

H2@Scale Program: This program, launched by the US Department of Energy (DOE), aims to develop and commercialize hydrogen energy technologies [18:46]. It includes research and development, demonstration projects and industry partnerships to integrate hydrogen systems into a variety of sectors, including power generation, transportation and industrial applications.[14].

National Hydrogen and Fuel Cell Laboratory: This laboratory complex, located in New York City, provides unique capabilities for the research, development and testing of hydrogen technologies. It conducts research into water electrolysis, hydrogen storage, fuel cells and other related technologies.

The H2USA initiative is a partnership between government, industry, and other stakeholders to develop hydrogen energy infrastructure in the United States [11]. Members of this partnership are working together to create the conditions for the deployment of hydrogen energy technologies, including the development of standards, certification and information exchange[15].

14 U.S. Department of Energy. (n.d.). H2@Scale. Available from: https://www.energy.gov/eere/fuelcells/h2scale

15 United States Department of Energy, July 2016. Available from: https://www.energy.gov/sites/default/files/2016/07/f33/fcto_h2usa_factsheet.pdf

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Fuel Cell Technologies Office Program: This DOE program focuses on the research, development, and demonstration of fuel cell technologies, including hydrogen fuel cells. It supports projects in transportation, stationary applications and energy efficiency systems to improve the performance and reduce the cost of fuel cell technologies.

The Hydrogen and Fuel Cells Program works in collaboration with industrial partners, academic institutions and research organizations to develop and implement new technologies. The goal of the program is to create economically competitive and sustainable hydrogen energy solutions that can be used in various sectors such as energy, transport and industry.

Programs and initiatives in the United States are aimed at stimulating the development and implementation of hydrogen technologies, creating the necessary infrastructure and improving technological solutions in this area. Thanks to this approach, the United States is actively promoting the development of hydrogen energy and playing an important role in shaping the global market for hydrogen technologies [18].

In Japan, there are several programs aimed at developing hydrogen energy. Japan actively supports the industrial, research and infrastructure development of hydrogen technologies. Listed below are some of them.

Hydrogen Infrastructure Development for the Sustainable Energy System: this program, led by the Ministry of Economy, Trade and Industry (METI) of Japan, specifically develops hydrogen infrastructure to support the deployment of hydrogen technologies. As part of the program, hydrogen filling stations are being built, hydrogen storage and delivery systems are being developed, and research is being conducted to optimize infrastructure[16].

Hydrogen Fuel Cells and Hydrogen Storage Technologies Program: this program, run by the National Institute of Industrial Science and Technology (AIST), focuses on research and development in hydrogen fuel cells and hydrogen storage technologies. The goal of the program is to increase the efficiency of fuel cells, improve durability, develop new materials and hydrogen storage technologies[17].

Hydrogen Society Strategy Program: Japan has developed a hydrogen society strategy to accelerate the adoption of hydrogen technologies in various sectors, including energy, transport and industry. The strategy includes financial support and subsidies for research, development and demonstration projects in hydrogen and fuel cells [17][18].

Hydrogen Energy Islands Program: plans to be regions fully equipped with hydrogen infrastructure, including hydrogen production, storage, transportation and use. They will use hydrogen in various fields such as electricity, transport, industry and domestic purposes. The Hydrogen Energy Islands program is part of Japan's hydrogen energy

16 Analyzing the necessity of hydrogen imports for net-zero emission scenarios in Japan. Available from: https://www.sciencedirect.com/science/article/pii/S0306261921006814

17 Japan Science and Technology Agency - "Hydrogen and Fuel Cells - Toward a Sustainable Hydrogen Society". Available from: https://www.jst.go.jp/kisoken/presto/hydrogen/en/index.html

18 Japan's Ministry of the Environment - "Hydrogen Society". Available from: https://www.env.go.jp/en/focus/attach/060403-5.pdf

development strategy and aims to create model regions where hydrogen technologies will be widely used and demonstrated (20)[19].

In the European Union (EU), there are several programs and initiatives aimed at developing hydrogen energy to reduce dependence on hydrocarbons [9:151]. The EU actively supports research, development and demonstration projects related to hydrogen technologies. Some of them are listed below.

EU Recovery and Resilience Plan (Next Generation EU): As part of this plan, the EU is committing significant investments to the development of hydrogen energy. The goal is to create a sustainable, competitive and innovative hydrogen economy that can reduce greenhouse gas emissions and accelerate the clean energy transition [16].

EU Hydrogen Strategy: ehis strategy, introduced in 2020, identifies hydrogen as a key element in achieving the EU's climate and energy goals. The strategy sets goals for developing the hydrogen economy, including increasing hydrogen production, deploying hydrogen infrastructure and supporting hydrogen technologies across industries.

Fuel Cells and Hydrogen Joint Undertaking also funds and supports research, development and demonstration projects in the field of hydrogen storage systems. It promotes the development of fuel cell technologies and hydrogen storage systems, as well as their commercialization.

European Clean Hydrogen Alliance: In 2020, the European Commission launched this initiative to mobilize investment and promote the development of hydrogen energy in Europe [12:57]. The Alliance brings together various stakeholders, including businesses, research organizations, government institutions and public organizations, to create concrete projects and solutions in the field of hydrogen energy.

Clean Energy for All Europeans: This program, led by the European Commission, includes measures to stimulate the development of clean energy sources, including hydrogen energy [14]. It aims to achieve energy efficiency, reduce greenhouse gas emissions and create a sustainable and competitive energy system in Europe[20].

These programs in the European Union show great plans and strategic attention to the development of hydrogen energy. The focus is on producing clean green hydrogen without carbon emissions [3]. They aim to create an enabling environment for innovation, deploying hydrogen infrastructure, developing new technologies and attracting investment in this promising area.

In Russia, rich in natural resources and energy, the need to develop hydrogen energy is also important, since the future of the country as a global energy power directly depends on it. Russian scientists note that energy directly affects geopolitics. Thus, the basis of geopolitics of the 19th and 20th centuries. lies steam and coal power. During the transition to the fourth industrial revolution, the features of which have not yet been precisely defined, it is important to study what will develop it, including hydrogen energy [1:49]. In the event

19 Ministry of Economy, Trade and Industry (METI) – "Hydrogen Energy Island Concept". Available from: https://www.meti.go.jp/english/press/2021/0108_002.html

20 European Commission – "A hydrogen strategy for a climate-neutral Europe". Available from: https://ec.europa.eu/energy/topics/energy-strategy-and-energy-union/hydrogen-strategy_en

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of a world transition to hydrogen and an increase in the share of electricity generation from it, Russia can also maintain its leading position in the energy market and become a global exporter of hydrogen [5:216] in combination with natural gas, which, even with a decrease in the share of oil in energy consumption, will remain demand.

Programs and strategies for hydrogen energy in Kazakhstan

There are several programs in Kazakhstan aimed at developing hydrogen energy. Kazakhstan is actively researching and implementing hydrogen technologies in its energy system. Some of them are listed below.

Strategy Kazakhstan Energy 2050: this is a long-term plan for the development of the energy sector of Kazakhstan, includes the development of hydrogen energy as one of the key areas. The goal of the strategy is to increase energy efficiency and use clean energy sources, including hydrogen.

In 2013, specific goals for the development of the renewable energy sector were formulated and, as a result, the volume of the renewable energy market and the potential for reducing greenhouse gases from renewable energy sources were determined. The Concept of Kazakhstan's transition to a green economy and the Kazakhstan 2050 Strategy have goals to increase the share of alternative and renewable energies in the country's energy balance to 3% in 2020, to 15% in 2030, and to 50% in 2050[21].

National Hydrogen Energy Development and Introduction Program: this program was launched with the goal of developing and introducing hydrogen energy in Kazakhstan. It includes research, development and projects in the field of hydrogen technologies, including the production, storage, transportation and use of hydrogen.

Kazakhstan plans to create a hydrogen cluster - an innovation center that brings together enterprises, research organizations and government institutions for cooperation and development of hydrogen technologies. The cluster will facilitate the exchange of knowledge, the development of new technologies and the creation of favorable conditions for the deployment of hydrogen infrastructure.

Kazakhstan is also actively developing international cooperation in the field of hydrogen energy. As part of this cooperation, the country conducts joint research, exchanges experience and best practices with other countries and international organizations.

For example, Kazakhstan cooperates with Japan, which has extensive expertise in the field of hydrogen energy. In 2019, Kazakhstan and Japan signed an agreement on cooperation in the field of hydrogen energy, which provides for the exchange of technical knowledge, experience and technologies, as well as the joint implementation of projects[22].

Kazakhstan is also actively involved in the work of the International Hydrogen Energy Agency (IPHE), which is an international platform for cooperation in the field of hydrogen

21 Development of renewable energy sources. Available from: https://www.gov.kz/memleket/entities/energo/activities/4910?lang=ru

22 On the signing of the Agreement between the Government of the Republic of Kazakhstan and the Government of Japan on cooperation in the field of peaceful uses of atomic energy and the Agreed Protocol thereto.Available from: https://adilet.zan.kz/rus/docs/P100000093_

energy. Within the framework of IPHE, Kazakhstan exchanges information and experience with other participating countries, participates in joint research projects and program initiatives. The German-Swedish company SVEVIND Energy Group intends to invest $50 billion in the production of green hydrogen in Kazakhstan. This will allow the production of up to 3 million tons of hydrogen[23].

All of these programs, strategies and international cooperation in the field of hydrogen energy reflect Kazakhstan's commitment to developing clean energy sources and creating a sustainable energy system [7]. Kazakhstan recognizes the potential of hydrogen energy and is actively working to implement it in its national energy strategy.

Conclusion

This article examined the world experience of countries that developed hydrogen energy more than others and explored the experience of Kazakhstan, achievements and problems. There is a growing interest in hydrogen energy around the world. Many developed countries are actively investing in research and development in this area, developing national strategies and legislation to promote the development of the hydrogen economy. Countries such as Germany, Japan, South Korea and Australia are already implementing projects related to the production, storage and use of hydrogen [4:36].

One important trend is the increasing scale of hydrogen production from renewable energy sources such as solar and wind energy. Electrolysis technologies, which produce hydrogen from water using electricity, are becoming increasingly efficient and cost-effective.

Demand for hydrogen is growing in various sectors, including transport, industry and energy. Hydrogen fuel cells are becoming increasingly popular in the automotive industry, used in manufacturing and as a source of electrical energy.

Kazakhstan, possessing vast reserves of natural resources and significant potential for the development of renewable energy sources, has all the prerequisites for the development of hydrogen energy. The country is already implementing projects to produce hydrogen based on renewable energy sources such as solar and wind energy. These projects improve energy efficiency and reduce greenhouse gas emissions.

Kazakhstan is actively developing a legislative framework and national strategies in the field of hydrogen energy. The country's authorities provide financial support and tax incentives for investors who are interested in developing this sector. This creates a favorable environment for investment and stimulates the development of hydrogen infrastructure.

Kazakhstan has significant research potential in the field of hydrogen energy. There are scientific institutes in the country that are engaged in research and development of new technologies in this area. This promotes innovative solutions and ways to optimize hydrogen production processes.

23 $50 billion project: Kazakhstan begins to produce green hydrogen. Available from: https://el.kz/ru/proekt-na-50-mlrd-dollarov-kazahstan-nachinaet-proizvodit-zelenyy-vodorod_79364/

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However, the development of hydrogen energy in Kazakhstan faces obstacles:

- for the successful implementation of hydrogen projects, it is necessary to develop the appropriate infrastructure, including production facilities, networks for transportation, storage and refueling of hydrogen. Building such an infrastructure requires significant investment and strategic planning.
- the cost of hydrogen production and related technologies remains high. There is a need to reduce production costs, improve process efficiency and develop business models that are economically viable.
- the development of hydrogen energy requires the presence of qualified specialists who will be familiar with modern technologies, methods and safety in this area. Educational programs and trainings must be developed to prepare the necessary specialists.
- cooperation with international partners can play an important role in the development of hydrogen energy. Exchange of experience, technologies and best practices with other countries active in this area can contribute to faster development in Kazakhstan.

All this requires an integrated and coordinated approach on the part of government, business, scientific and educational institutions.

Given favorable conditions and the right strategy, Kazakhstan can become a leader in the field of hydrogen energy in the region and make a significant contribution to the global development of this industry. The development of hydrogen energy in Kazakhstan contributes to the achievement of national and international goals in the field of sustainable development, reducing greenhouse gas emissions and reducing dependence on unstable energy sources.

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Contribution of the author

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