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ТУРУКТУУ ЭНЕРГЕТИКАЛЫК ӨТҮҮ ҮЧҮН ЖАШЫЛ СУУТЕК: ДҮЙНӨЛҮК БАГЫТТАР, ТЕХНОЛОГИЯЛАР ЖАНА СТРАТЕГИЯЛЫК ЖОЛДОР

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ЗЕЛЁНЫЙ ВОДОРОД КАК КАТАЛИЗАТОР УСТОЙЧИВОГО ЭНЕРГЕТИЧЕСКОГО ПЕРЕХОДА: ГЛОБАЛЬНЫЕ ТРЕНДЫ, ТЕХНОЛОГИИ И СТРАТЕГИЧЕСКИЕ НАПРАВЛЕНИЯ

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GREEN HYDROGEN AS A CATALYST FOR SUSTAINABLE ENERGY TRANSITION: GLOBAL TRENDS, TECHNOLOGIES, AND STRATEGIC PATHWAYS

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Аннотация. Жашыл суутек туруктуу жана аз көмүртектүү энергетикалык системаларга глобалдык өтүүнүн негизги элементине айланууда. Макалада Германиянын лидерлигине басым жасоо менен суутек энергетикасын өнүктүрүүнүн эл аралык тенденциялары талданат жана реалдуу пилоттук RefLau (Referenzkraftwerk Lausitz) долбоору – декарбонизациялоо стратегиясынын алкагында Лаусиц (Бранденбург) көмүр аймагында ишке ашырылган эталондук суутек электр станциясы. RefLau энергиянын кайра жаралуучу булактарын, электролизди, сактоону жана кошумча продуктуларды кайра колдонууну пайдалануу менен комплекстүү жашыл суутек өндүрүүнүн модели. Ал ошондой эле «көк» суутектен «жашыл» суутекке акырындык менен өтүүнү болжолдогон Казакстандын стратегиясын инфраструктурасы жана отун ресурстары өнүккөн өлкөлөр үчүн реалдуу жол катары карайт. Өзгөчө көңүл олуттуу гидроэнергетикалык потенциалга ээ Кыргызстанга бурулууда.

Негизги сөздөр: жашыл экономика, туруктуу өнүгүү, экономика, интеграция, ресурстар, глобалдык экономика.

Аннотация. Зеленый водород становится ключевым элементом глобального перехода к устойчивым и низкоуглеродным энергетическим системам. В статье анализируются мировые тенденции развития водородной энергетики с акцентом на лидерство Германии и реальный пилотный проект RefLau (Referenzkraftwerk Lausitz) — эталонная водородная электростанция, реализованная в угольном регионе Лаузиц (Бранденбург) в рамках стратегии декарбонизации. RefLau — это модель комплексного производства зеленого водорода с использованием возобновляемых источников энергии, электролиза, хранения и повторного использования побочных продуктов. Также рассматривается стратегия Казахстана, предполагающая постепенный переход с «голубого» на «зеленый» водород, как реалистичный путь для стран с развитой инфраструктурой и топливными ресурсами. Особое внимание уделено Кыргызстану, обладающему значительным гидроэнергетическим потенциалом.

Ключевые слова: зеленая экономика, устойчивое развитие, экономика, интеграция, ресурсы, мировая экономика.

Abstract. Green hydrogen is becoming a key element in the global transition to sustainable and low-carbon energy systems. The article analyzes international trends in the development of hydrogen energy with an emphasis on the leadership of Germany and the real pilot project RefLau (Referenzkraftwerk Lausitz) - a reference hydrogen power plant implemented in the coal region of Lausitz (Brandenburg) as part of the decarbonization strategy. RefLau is a model for integrated green hydrogen production using renewable energy sources, electrolysis, storage and reuse of by-products. It also considers the strategy of Kazakhstan, which assumes a gradual transition from «blue» to «green» hydrogen, as a realistic path for countries with developed infrastructure and fuel resources. Particular attention is paid to Kyrgyzstan, which has significant hydropower potential.

Key words: green economy, sustainable development, economy, integration, resources, global economy.

Against the backdrop of accelerating climate change and the global drive for carbon neutrality, green hydrogen is becoming one of the most promising energy sources of the 21st century. The first studies in the field of hydrogen energy began in the 1980s and were associated with the development of high-temperature nuclear reactors and steam reforming technologies for natural gas [1]. However, a real surge of interest in hydrogen as an environmentally friendly energy source began after the signing of the Kyoto Protocol (1997) and the Paris Agreement (2015), which outlined the need to radically reduce greenhouse gas emissions.

The concept of a hydrogen economy, proposed by John Bockris in the 1970s, anticipated a future in which hydrogen would become a universal energy source suitable for storage, transportation and use in various sectors. Today, this vision is becoming increasingly real due to the growth of renewable energy sources (RES) and the need to decarbonize sectors that are difficult to directly electrify. Hydrogen produced by water electrolysis using renewable energy sources, so-called “green” hydrogen, is a carbon-free solution that meets international sustainability goals [2].

Germany is a leader in shaping the hydrogen agenda: in the 2021 coalition agreement and the updated National Hydrogen Strategy, the country declared its intention to become a global hub for hydrogen technologies by 2030 [3]. In addition to government initiatives, the private sector, in particular Hy2gen AG, is actively developing the industrial production of green hydrogen and synthetic fuels in Europe and other regions.

A typical example of the successful implementation of hydrogen technology in Germany is the RefLau (Referenzkraftwerk Lausitz) project, a reference hydrogen power plant located in the Lausitz region of Brandenburg. This project integrates renewable energy sources, hydrogen electrolysis, storage and use of oxygen and heat, thereby demonstrating the principles of a closed energy cycle. RefLau produces green hydrogen from solar and wind energy and uses it for energy, transport and industry. The project serves as a model for sustainable energy transition and plays an important role in transforming a coal region into a green energy hub [4].

Regions with rich renewable energy potential, such as Australia, North Africa and South America, are very active in the international arena and are striving to become key exporters of

green hydrogen [5]. Despite the growing interest, the development of hydrogen energy faces a number of challenges, including high production costs, the need to create appropriate infrastructure and concerns about the use of water resources in large-scale electrolysis [2], [6].

This study aims to analyze the current scientific discourse on green hydrogen, with an emphasis on technological developments, international strategies and the experience of Germany, in particular using the RefLau project as an example. Based on a review of current literature and policy documents, the article formulates conclusions and recommendations that may be useful for the formation of a hydrogen strategy in developing countries, including the Central Asian region.

Discussion

Kazakhstan's experience is of considerable interest to other Central Asian countries, including Kyrgyzstan, in assessing the potential of hydrogen energy. According to A.E. Ibraeva [7], Kazakhstan has significant prerequisites for the development of a hydrogen economy due to its vast territory, favorable conditions for the development of renewable energy, and the presence of a developed oil and gas infrastructure.

Despite the insufficient technical and regulatory framework for the production, storage, and transportation of hydrogen, the country has realized the strategic importance of participating in the global hydrogen agenda. In the context of the expected growth in global demand for environmentally friendly hydrogen, especially from the European Union, Kazakhstan can occupy a profitable export niche.

Nevertheless, the publication also points out serious challenges: the low level of development of renewable energy sources, a shortage of personnel and competencies, the lack of carbon capture and storage (CCUS) technologies, as well as the risk of water shortage. In this regard, the author proposes a step-by-step approach to the development of the hydrogen industry:

In the short and medium term, the focus should be on blue hydrogen produced using natural gas with subsequent CO_2 capture and storage. This approach allows for the use of existing infrastructure and the acquisition of important practical experience in the transportation and storage of hydrogen.

In the long term, priority should be given to green hydrogen produced by water electrolysis using renewable energy sources, both for domestic consumption (decarbonization of energy, industry and transport) and for export under international climate agreements.

The experience of Kazakhstan emphasizes the importance of strategically choosing the type of hydrogen and creating favorable conditions for technological and infrastructural development. These findings are also relevant for Kyrgyzstan, which, despite its smaller scale, has comparable conditions and capabilities, including in the field of hydropower and decentralized renewable energy systems.

Kyrgyzstan and Germany: Synergy of Interests in Green Energy

Along with regional examples, Germany's experience in the field of renewable energy and green hydrogen production is of great importance for Kyrgyzstan. During official negotiations with German Federal President Frank-Walter Steinmeier, Kyrgyz President Sadyr Japarov emphasized that the country is interested in Germany's advanced technologies for organizing the production of environmentally friendly hydrogen based on the country's water resources.

A typical example of the application of such technologies is the RefLau (Referenzkraftwerk Lausitz) project in Germany - a pilot hydrogen power plant being implemented in the post-coal region of Lausitz. The project combines the generation of electricity from renewable energy sources, electrolysis, storage and use of hydrogen, oxygen and heat, demonstrating the principles of a closed energy cycle and sustainable regional development. RefLau serves as a model for an effective transition from a carbon economy to a low-carbon one and can be useful for countries with high hydro potential, such as Kyrgyzstan [4].

The Kyrgyz-German Business Council, established in 2022, is seen as an important platform for bilateral technological and investment cooperation. These initiatives open up prospects not only for the introduction of German technologies in Kyrgyzstan, but also for broader Central Asian cooperation in the field of green energy.

Thus, the vector of cooperation with Germany, combined with regional practices, such as Kazakhstan's strategy, can become the basis for the formation of a sustainable hydrogen policy for Kyrgyzstan based on international experience,

regional specifics and low-carbon development priorities.

Results

The analysis highlights the growing global importance of green hydrogen as a driver of sustainable energy transition and a key element of decarbonization strategies in both developed and developing countries. An examination of international experiences, in particular Germany's leadership in hydrogen technologies and the RefLau project, shows that the integration of renewable energy with electrolysis, storage and reuse systems can serve as a viable model for countries transitioning from fossil fuels to clean energy.

The RefLau project in Germany demonstrates how regions previously dependent on the coal industry can be transformed into hydrogen clusters. This example illustrates the practical feasibility of creating a closed-loop hydrogen system based on renewable electricity and offers valuable technical and institutional lessons for countries like Kyrgyzstan, which have significant hydropower potential but do not yet have the necessary technological infrastructure.

Kazakhstan's step-by-step approach to developing the hydrogen industry — starting with blue hydrogen and then moving to green — is a realistic model for countries rich in fossil fuels and with the relevant infrastructure. This example is also relevant for Kyrgyzstan, which is seeking to balance its renewable energy potential with existing infrastructure and investment constraints.

In addition, the Kyrgyz leadership has expressed interest in developing green hydrogen and in advanced German technologies. The establishment of the Kyrgyz-German Business Council and the call for expanded technological cooperation demonstrate the country's readiness to take a position in the emerging hydrogen economy. These steps, combined with favorable natural conditions and growing international demand, create a unique window of opportunity for Kyrgyzstan: develop domestic production of green hydrogen; attract international partnerships and investments; promote regional energy security and achieve climate goals; explore export potential, especially towards Europe and Asia.

Ultimately, the combination of regional best practices (Kazakhstan), advanced international models (Germany) and local political support (Kyrgyzstan) forms a solid foundation for the gradual and strategic development of hydrogen energy in Central Asia.

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