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PROSPECTS FOR USING HYDROGEN AS A RENEWABLE ENERGY SOURCE

ПЕРСПЕКТИВИ ВИКОРИСТАННЯ ВОДНЮ ЯК ВІДНОВЛЮВАЛЬНОГО ДЖЕРЕЛА ЕНЕРГІЇ

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Abstract. *This article discusses the potential of hydrogen as a renewable energy source. Here, the importance of the development of hydrogen energy in the context of energy, environmental and climate problems of today is shown. The history of hydrogen, its types, the simplest method of extraction are discussed. The experience of different countries in using hydrogen as a renewable energy source is also highlighted. In addition, the prospects for the use of this fuel in Ukraine, the advantages of hydrogen compared to traditional energy sources are explored, and the need for state support and international cooperation to achieve the full potential of this renewable resource is emphasized. The article calls for attention and investment in the development of hydrogen energy as a key aspect of creating a sustainable and clean energy future.*

Keywords: *hydrogen, alternative energy sources, environment, energetics, climate, fossil fuel.*

Introduction.

Modern society until the end of the 20th century faced energy problems that led to some extent even to crises. All traditional sources of energy will surely run out, especially with the constantly growing needs of people. Humanity is trying to find new sources of energy that would be beneficial to everyone's relations: ease of extraction, cheapness of transportation, environmental cleanliness and renewability.

An equally important reason for the need to develop alternative energy sources is environmental and climate problems, in particular the global problem warming Its essence lies in the fact that carbon dioxide (CO2), released during the burning of coal, oil and gasoline, creates the so-called greenhouse effect.

Substantial aggravation of energy and environmental problems, which is observed both in Ukraine and throughout the world, brings to the fore the problem of wider use of alternative energy sources. One of these in the world, while at the pilot stage, is the introduction of the hydrogen energy industry.

It is known that hydrogen is the most common element on the earth's surface and beyond. Therefore, hydrogen is an extremely energy-intensive resource. He burns at the same temperature as natural gas. At the same time, during combustion, substance per unit mass releases almost 3.5 times more heat than when hydrocarbon oil or coal are burned. Hydrogen fuel is much more efficient than diesel or aviation fuel. Moreover, hydrogen as the resource contains a high ecological value, since the product of its combustion is water.

Therefore, in this article, we will consider the prospects of using hydrogen as an energy source.

History of Hydrogen. Hydrogen was first identified as an element in 1766 by the British scientist Henry Cavendish after he isolated hydrogen gas by reacting metallic zinc with hydrochloric acid. In 1788 building on the discoveries of Cavendish, French chemist Antoine Lavoisier gave hydrogen its name, which was derived from the Greek words - “hydro” and “genes,” meaning “water” and “born of.” In the 1920s, the German engineer Rudolf Erren redesigned the interior internal combustion engines of trucks, buses and submarines to use hydrogen or hydrogen mixtures. British scientist and Marxist writer J.B.S. Haldane introduced the concept of renewable hydrogen in his article “Science and the Future”, suggesting that “the will large power plants where there is excess during windy weather electricity will be used for the electrolytic decomposition of water on oxygen and hydrogen". In 1973 the OPEC oil embargo and the resulting supply shock suggested that the era of cheap petroleum had ended and that the world needed alternative fuels. In 1990, the world's first hydrogen production plant based on solar cells Solar-Wasserstoff-Bayern, research and testing center in south Germany began to act [1].

Simplest method of producing hydrogen. Hydrogen is a gas that can be obtained from water. It is the simplest and lightest of all chemical elements, which is an ideal fuel. When hydrogen is burned, water is formed, which can be decomposed again into hydrogen and oxygen, without any pollution of the environment. The method by which hydrogen can be extracted from water is called electrolysis. In figure 1 we can see two electrodes, which are inserted in a tank filled with water; a cathode that carries a negative charge in addition to an anode that carries the opposite charge. In order to start the decomposition an electric current is passed through the electrodes. Hydrogen will leave the apparatus in the side where the cathode is located, as soon as it is positively charged in the water molecule [1].

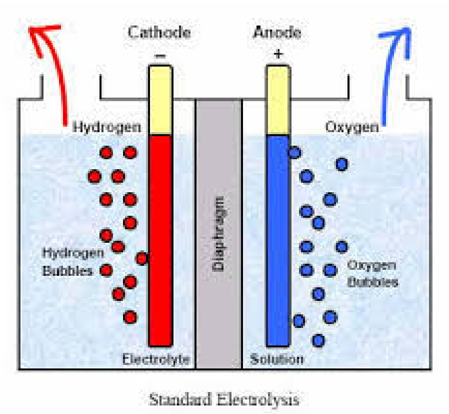

Figure 1. Hydrogen production using electrolysis

Type of hydrogen. Hydrogen is often classified by different colours to describe its production technologies, e.g. green, grey, blue, etc. As the process can differ in the type of energy used, the production costs and associated emissions can be very different. We will consider the main colours: grey, green, blue, blue, turquoise and purple.

Grey hydrogen. Currently, grey hydrogen is the most common. Grey hydrogen produced by steam reforming of natural gas or coal gasification without carbon capture, use and storage (CCUS). According to statistics, more than 40% of grey hydrogen is a by-product of other chemical processes. Typically, hydrogen produced as a by-product is unofficially classified as white hydrogen by the North American Freight Efficiency Council. Grey hydrogen is in demand in the petrochemical industry and for ammonia production. And the demand for this hydrogen in these industries has grown over the past 70 years. The main disadvantage of grey hydrogen is the very high CO_2 emissions generated during hydrogen production. About 2% of the world's coal production and 6% of natural gas are used to produce grey hydrogen per year. Additional methods of hydrogen production include partial oxidation of methane (POM), partial oxidation (POX) of oil products and autothermal reforming (ATR). In the literature, this hydrogen is referred to as brown and black hydrogen [2].

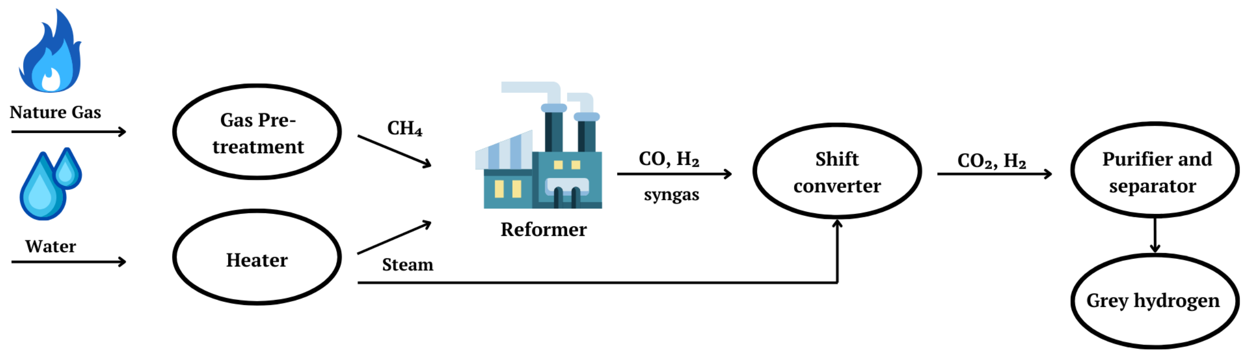

Figure 2. Schematic of the steam reforming of natural gas (SMR) production process

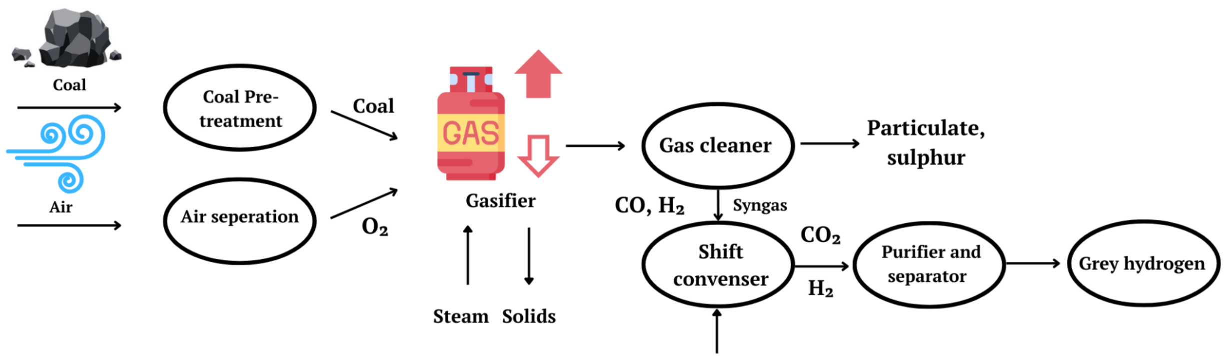

Figure 3. Schematic production process of coal gasification

Blue hydrogen. Blue hydrogen is produced by steam reforming methane using natural gas or biomass. For hydrogen to be considered blue, a hydrogen production facility only needs to install a CCUS device to capture it. The exact amount that needs to be captured is not defined. Today, blue hydrogen is seen as a technology before the full transition to green hydrogen, which is why carbon capture and sequestration has been intensively promoted for several years. Although this technology leads to emission reductions, it is far from ideal climate neutrality. At the moment, it is difficult to accurately state the environmental impact, as it largely depends on which parts of the hydrogen production process are included. It is known that blue hydrogen only halves grey hydrogen emissions [2].

Turquoise hydrogen. In contrast to the traditional hydrogen production methods already mentioned, the by-product of turquoise hydrogen via methane pyrolysis is solid carbon in the form of carbon filaments or carbon nanotubes, which can be used for further production process and is much easier to store, hence this type of hydrogen will leave a smaller carbon footprint. Methane pyrolysis, which can be divided into three categories of processes, namely thermal decomposition, plasma decomposition (Kwerner process) and catalytic decomposition, has been known for decades and has been technically implemented in several processes. However, only in recent years has there been a growing interest in hydrogen production mainly by thermal decomposition as the most developed process.

Green hydrogen. Green hydrogen is a new technology that solves the problem of greenhouse gas pollution. This hydrogen is produced from water by electrolysis using electricity from renewable sources. Due to its diverse applications, green hydrogen plays an important role in the transition to net zero.

Net zero is the ideal state when the amount of greenhouse gases emitted into the atmosphere is equal to the amount absorbed. To prevent the planet from continually - and catastrophically - warming, all industries must achieve net zero emissions.

Also, industries that are highly dependent on fossil fuels, such as heavy industry or transportation, will benefit greatly from green hydrogen [2, 3].

Purple hydrogen. Purple hydrogen can be produced by electrolysis using an atomic current. Although hydrogen production from nuclear electricity is not in demand in European hydrogen strategies, it could be a practical alternative in some regions of the world. Also, the construction of a hydrogen production plant could solve the problem of nuclear power plants being phased out and provide additional energy storage capacity when seasonal storage is needed. In some literature, violet hydrogen is also called yellow hydrogen. However, a more common description of yellow hydrogen for electrolysis using grid electricity [2].

The basic types of hydrogen are shown in figure 4.

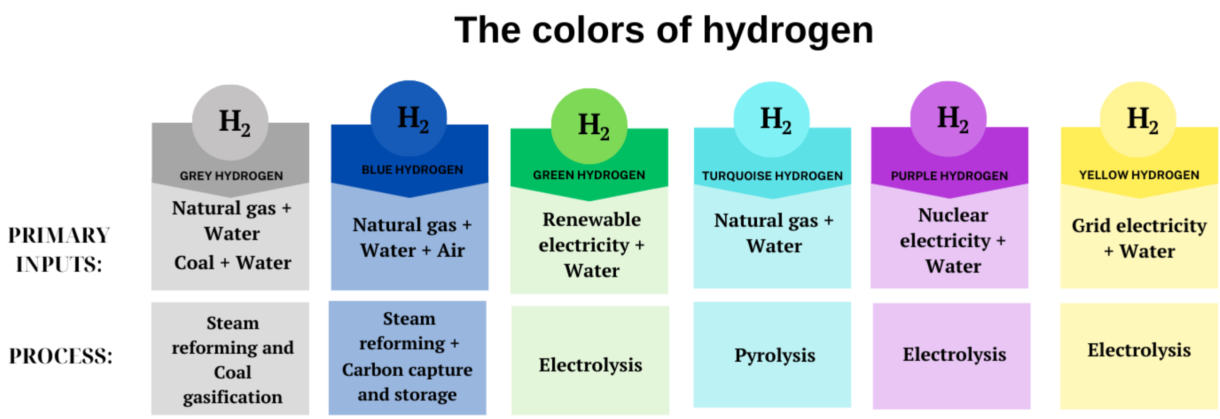

Figure 4. Hydrogen colors

Other hydrogen colours. The most developed methods of hydrogen production today are thermochemical conversion processes of biomass, with gasification being the most explored technology for hydrogen production from biomass. Various biological technologies such as microbial electrolysis and dark fermentation are also being investigated. To date, very little hydrogen has been produced from biomass, which is the reason why this process has not been assigned a separate colour, according to various scientists.

Researchers have identified two more colours of hydrogen: aqua and white. Aqua hydrogen is produced from oil sands and oil fields using a new process that does not emit carbon dioxide. The colour was chosen as a middle ground between blue and green, which means that hydrogen is produced from fossil fuels (blue) but without carbon emissions (green). White hydrogen is the direct splitting of water molecules using concentrated solar energy. But these colours are still at the basic research stage and will be tested and applied in Saudi Arabia [2].

Experience of different countries in the use of hydrogen. January 2022, the International Renewable Energy Agency (IRENA) releases the report "The Geopolitics of Energy Transition: The Hydrogen Factor", which analyses the political and economic changes taking place in the energy sector. It lists the leading countries that are promoting the initiative to switch to clean hydrogen fuel.

China. China is a leader in hydrogen consumption and production, with an annual consumption of over 24 million tonnes. However, the country mostly produces grey hydrogen, which is made from fossil fuels, but since 2019, green hydrogen projects have been actively developed.

China also has the world's third-largest fleet of fuel cell electric vehicles (FCEV), and published its first hydrogen roadmap in 2016. This country is very active in the development of fuel cell trucks and buses [4].

The United States of America. The US is the second largest hydrogen producer and user in the world after China, accounting for 13% of global demand. Some states, such as California, have been supporting the growth of the FCEV market in the country for more than a decade through various initiatives, such as the Clean Vehicle Rebate Programme. The US was the world leader in this area until 2020 [4, 5].

Japan. In 2017, Japan became the first country to present a national hydrogen strategy as part of its ambition to become the world's first "hydrogen society" by introducing this fuel in all industries.

The Japanese government supports this initiative and is willing to invest in hydrogen and fuel cell technologies. For example, in 2020, the government set mobility targets of 800,000 FCEV and 900 hydrogen filling stations by 2030, totalling $670 million.

However, the country mostly imports hydrogen from abroad as it lacks the resources to produce green hydrogen on a large scale [4, 5].

South Korea. South Korea has identified green hydrogen as a key driver of economic growth for 2019. The country aims to become a global leader in the production and deployment of FCEV and large-scale stationary fuel cells for hydrogen energy production.

Its Green New Deal contains an ambitious target of deploying 200,000 FCEVs by 2025, 20 times the 2020 figure.

Last year, South Korea passed a law aimed at promoting hydrogen vehicles, charging stations and fuel cells.

The government has ambitious plans for the future to meet the country's energy needs, for example, by 2030, hydrogen will supply 10% of the country's cities, counties and towns, by 2040 its share will increase to 30%, and by mid-century it will become the largest single source of energy in the country [4, 5].

The European Union. The EU has quite ambitious goals in the European Green Deal, where the hydrogen strategy is the basis for achieving the main goal. For example, by 2023, the Union aims to install 40 gigawatts of renewable hydrogen electrolysis capacity.

The European Clean Hydrogen Alliance has been established to support investment and scale-up of green hydrogen projects, as the European Union aims to become an industrial leader in clean hydrogen. Different member states have the potential to become major exporters, importers or transit hubs for hydrogen.

India. Green hydrogen could help India take a big step towards energy independence. As the country begins to shift towards renewable energy sources and away from imported fossil fuels.

The government is considering legislative changes that would require refineries and fertiliser producers to use a minimum quota of green hydrogen in their production [5].

Other countries. Countries such as Chile, Morocco and Namibia are major exporters of emission-free green hydrogen. At the same time, fossil fuel exporters such as Oman, the United Arab Emirates (UAE) and Saudi Arabia are eager to use clean hydrogen to diversify their economies [4, 5].

Prospects for using hydrogen as a fuel in Ukraine. Ukraine has many opportunities for relatively cheap production of renewable energy. Hydrogen can be considered a universal fuel for vehicles. It is absolutely ecologically clean. Hydrogen can replace gasoline, diesel fuel and fuel oil in all types of heat engines. The European Hydrogen Strategy, which is part of the European Green Deal adopted in 2020 by the European Parliament, makes transitioning to a green hydrogen economy a key goal. Its overall purpose is to make Europe climate neutral by 2050.This strategy can protect biological diversity, and green the economy. Ukraine possesses the prerequisites for large-scale and export-oriented green hydrogen production. Besides, Ukraine has strong points for building a hydrogen economy: a favourable geographical location, large nuclear power plants, the presence of steel, fertilizer and cement production, an extensive gas transportation network, large geological gas storage facilities near the EU. Ukraine's natural gas storage system is the third largest in the world in terms of capacity and allows storing fuel not only for the country, but also for the EU. In the 2x40 GW Initiative, Hydrogen Europe proposes a strategy for a fast scale-up of the hydrogen economy in the EU. The strategy proposes the installation of 8 GW electrolyser capacity destined for export, 21 TWh of green hydrogen, which is 12% of the EU demand in 2030 outlined in the European Hydrogen Roadmap, could be produced annually, assuming 3,500 full load hours operating at an efficiency rate of 75%. Given Ukraine's status as a candidate for EU membership and the requirements of the "European Green Course", the development of the hydrogen economy is of strategic importance for the country. Hydrogen energy would contribute to the solution of problems in recovery of Ukraine's economy, especially against the background of Russia's war against Ukraine [6].

Challenges in the distribution of hydrogen. Hydrogen holds great promise for the future as an alternative, environmentally friendly and clean fuel. Every year, more and more global governments and companies are investing in hydrogen energy technologies. Hydrogen is a leak-prone gas with a powerful warming effect that is often ignored. To prevent this, hydrogen must be produced cleanly and used wisely.

Consider the main problems connected with hydrogen fuel:

1. *Hydrogen emissions*. Many people do not realise that hydrogen can contribute to global warming because when it is released into the atmosphere before being used or burned, it reacts with other chemicals to create a warming effect.

And humanity is only now beginning to understand how powerful this effect can be. For example, a study by scientists has shown that on a time scale of a decade or two, the power of hydrogen warming is much greater than previously recognised.

This poses a major challenge for the industry: as hydrogen molecules are so tiny, they are prone to leakage.

All of this suggests that minimising leaks should now be a priority for every hydrogen project.

One of the solutions to the leakage problem is to produce hydrogen close to the place of its operation, because the further the hydrogen has to be delivered, the greater the risk of leakage [7].

2. *Hydrogen production*. Currently, the hydrogen production process is energy-intensive and results in significant climate pollution.

However, green and blue hydrogen are produced under conditions that drastically minimise methane and CO_2 emissions.

Studies have shown that with high levels of green hydrogen leakage, climate performance will be better for another 20 years than with fossil fuel pollution, but not enough to be considered climate neutral.

Whereas in the case of blue hydrogen, with a large permanent leakage, this type of hydrogen will actually increase the 20-year warming impact.

So, if hydrogen production and distribution systems are not managed properly, this "clean" fuel can have a very bad impact on the climate in the short term [7, 8, 9].

3. *Impacts of hydrogen on societies*. When developing hydrogen projects, water consumption and air pollution from hydrogen production and use must be taken into account. For this reason, the development of hydrogen production should minimise harm to communities and society and address local concerns [7].

In the context of the global transition to clean energy, hydrogen is therefore best used where clean electricity cannot do the job on its own. Hydrogen can be used in heavy industry - for example, in steel and cement production - or as a feedstock for low-carbon fuels for ships and aircraft. In some cases, diverting electricity from the grid is not a sensible approach, as electricity can be used directly to meet these energy needs more efficiently and at lower cost.

Green hydrogen, which requires green electricity to produce, is currently in short supply and is likely to remain so for many years. Instead of placing big bets on hydrogen, renewable energy sources should be seriously considered.

The production of blue hydrogen from gas requires not only the prevention of methane emissions, but also the capture and storage of associated carbon dioxide, which is currently very limited.

The production of pure hydrogen is still a long way off, but as the industry continues to develop, it is important to ask the hard questions and make informed decisions to ensure that global investment in hydrogen is justified.

Conclusion.

Highlighting the prospects of using hydrogen as a renewable energy source, we can conclude that this direction has significant potential in solving energy, environmental and climate problems. Hydrogen, as the most abundant element, is an important resource for the future, as its use can help reduce dependence on traditional energy sources, reduce carbon dioxide emissions, and reduce negative environmental impacts.

Hydrogen energy shows great potential in the fields of transport, industry and life support. However, technological, economic and infrastructural challenges must be overcome in order to achieve the full development of this direction. This requires government support, investment in research and development, and promotion of international cooperation in the field of hydrogen energy.

Overall, hydrogen can be an important step towards creating a sustainable, efficient and clean energy future, and already today it deserves the attention and support from governments, scientific institutions and industrial enterprises.

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