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Problems and prospects for the development of hydrogen energy: The role and place of Russia

Alexey S. Kalmykov[1,2], Artem S. Vasilev[1,3], Daria S. Sokolan[1,4]

1 Peoples' Friendship University of Russia (RUDN University), Moscow, Russia.
2 kalmykov.alexey24@yandex.ru
3 art.astr7@gmail.com
4 dariya.kristi@yandex.ru, https://orcid.org/0000-0002-9883-6804

Abstract. The relevance of the study is due to the close attention of the world community to the issues of ecology and alternative energy. Currently, the climate agenda is one of the most important topics discussed around the world. In recent years, the leading countries of the world have been concentrating on the search for new energy sources, mainly focusing on solar energy and wind power, however, insufficient attention has been paid to hydrogen energy. The main goal of the climate agenda is to reduce greenhouse gas emissions into the atmosphere. Decarbonization can be achieved through the development of low-carbon industries and the transition to alternative energy sources such as hydrogen. The purpose of this work is to determine the prospects for the development of hydrogen energy and the introduction of hydrogen technologies in the real sector of the economy of the Russian Federation. Given the great dependence of the Russian Federation on traditional types of energy – oil and gas – today it is important to consider the possibility of switching to other sources of energy in order to ensure the energy security of the country in the future. The leading methods for the study of this problem are the analysis, systematization and grouping of information. The materials of the article can be used to develop the energy strategy of the Russian Federation in the future.
Key words: climate change, carbon dioxide, hydrogen energy, low carbon industries.

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Проблемы и перспективы развития водородной энергетики: роль и место России

Алексей Сергеевич Калмыков[5,6], Артем Сергеевич Васильев [5,7], Дарья Сергеевна Соколан [5,8]

5 Российский университет дружбы народов(РУДН), Москва, Россия.
6 kalmykov.alexey24@yandex.ru
7 art.astr7@gmail.com
8 dariya.kristi@yandex.ru, https://orcid.org/0000-0002-9883-6804

Аннотация. Актуальность исследования обусловлена пристальным вниманием мирового сообщества к вопросам экологии и альтернативной энергетики. В настоящее время климатическая повестка является одной из наиболее важных тем, обсуждаемых во всем мире. Последние годы ведущие страны мира концентрируются на поисках новых источников энергии, в основном акцент делается на солнечной энергетике и энергии ветряных станций, однако, водородной энергетике уделено недостаточное внимание. Основной целью климатической повестки является сокращение выбросов парниковых газов в атмосферу. Декарбонизация может быть достигнута за счет развития низкоуглеродных отраслей промышленности и перехода на альтернативные источники энергии, такие как водород. Целью данной работы является определение перспектив развития водородной энергетики и внедрения водородных технологий в реальный сектор экономики Российской Федерации. Учитывая большую зависимость Российской Федерации от традиционных видов энергии — нефти и газа — на сегодняшний день важно рассмотреть возможности перехода на другие источники энергетики, чтобы обеспечить энергетическую безопасность страны в будущем. Ведущими методами к исследованию данной проблемы являются анализ, систематизация и группировка информации. Материалы статьи могут быть использованы для разработки энергетической стратегии Российской Федерации в будущем.

Ключевые слова: изменение климата, углекислый газ, водородная энергетика, низкоуглеродные отрасли промышленности.

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Introduction

The relevance of this work is due to the fact that today the climate agenda plays a key role in the global economy. The main goal of the climate agenda is to reduce greenhouse gas emissions and develop low-carbon industries through the transition to clean energy generation and the creation of a closed carbon-free cycle economy.

Key energy carrier for a low-carbon economy which can be used for the accumulation, storage and transportation of energy. The main advantage of hydrogen is that hydrogen can be obtained from any source, incl. from carbon fuels, ensuring a minimal carbon footprint. There is an increased interest in the world in the hydrogen direction and decarbonization of the energy, industrial and oil and gas sectors using hydrogen. Countries such as: Germany, France, Canada, Japan, South Korea have already adopted appropriate strategies and roadmaps for the development of hydrogen energy, aimed at increasing the share of hydrogen use in various sectors of the economy and industry [Parnikovyy gaz zapushchen... 2020].

On April 22, 2016, Russian Federation has signed the Paris Agreement which was an important step for the development of a low-carbon economy in the Russian Federation [Paris Agreement 2015].

Russian Federation has significant opportunities for the production of hydrogen, its use in the energy sector and industry, having a number of competitive advantages and a serious potential in the field of hydrogen energy. The strategic documents of the Russian Federation set large-scale tasks in the field of formation and development of hydrogen energy. The Energy Strategy for the period up to 2035 determines the development of hydrogen production and the entry of the Russian Federation into the ranks of the world leaders in its production and export.

The main purpose of this work is to analyze development of hydrogen energy and recognize the place of Russia on the world stage.

Methodology

For achieving delivered goals in article are put and are solved two research tasks. First task: consider becoming hydrogen energy like alternatives traditional sources energy. With this purpose was held review and logical analysis:

- Analyzed need implementation hydrogen technologies in Russian industry;
- Analyzed current condition hydrogen technologies, and also perspective implementation hydrogen technologies in real sector economy;
- Highlighted the most effective ways receiving low carbon raw materials. Considered ways his receiving, storing, transporting and use in contemporary industrial sector;

Methods synthesis, analysis and systematization data were highlighted potential directions development hydrogen energy in Russian Federation:

- Analysis markets marketing energy hydrogen, on basis interest countries in his use;
- Ranking markets marketing hydrogen from most promising to less promising;
- Influence development hydrogen industry on the position Russian Federation in world economy.

Results

Hydrogen energy is one of the promising areas for the development of the state in the 21st century. Its spread may become one of the technological obstacles. Structural consistency carries huge costs and duplicates already existing energy systems. Figure 1 shows that multiple production and distribution pathways include multiple steps to make building a hydrogen infrastructure easier.

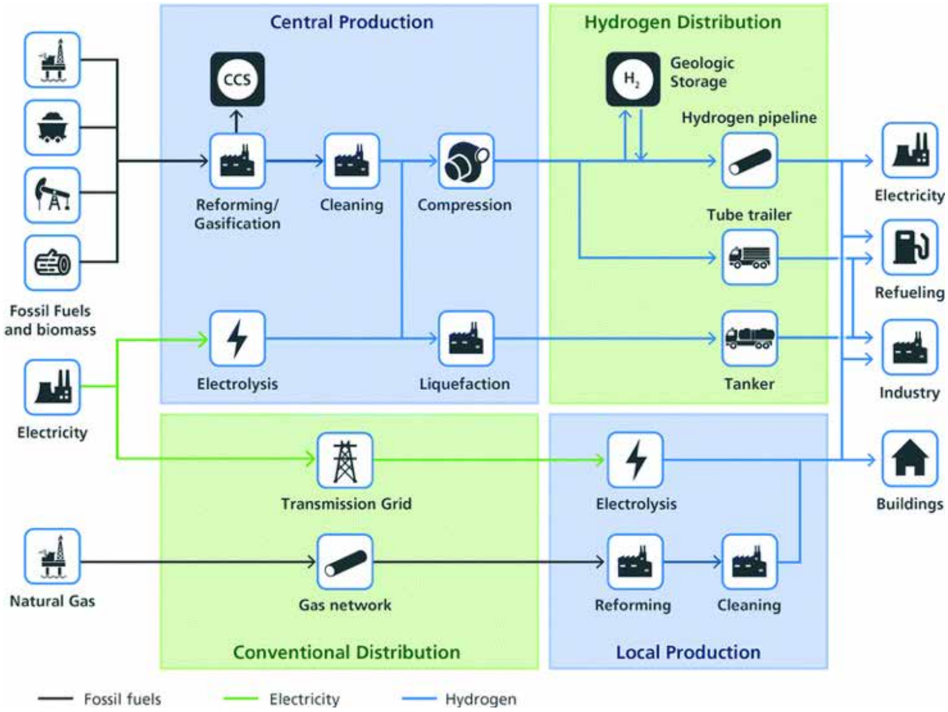

Figure 1. Visual diagram of the hydrogen infrastructure
Source [Staffell 2018]

Hydrogen production. The main obstacle in the development of the hydrogen sector is its production. Around the world, about 116 million tons of hydrogen are produced annually as a feedstock for the petrochemical and chemical industries, which is 5.4 – 7.8 EJ or ~ 1% of all world energy supplies. Considering this production volume 48% is from the steam reforming of natural gas to produce low-carbon hydrogen, about half is from the partial oxidation of crude oil and the remainder is from the electrolysis of water. There are also several other possibilities under development for obtaining the required hydrogen: 1) high temperature steam electrolysis, 2) solar thermochemical water splitting, 3) biological hydrogen production [FY 2019].

Most of the produced hydrogen comes from fossil fuels. The intensity of carbon dioxide emissions into the atmosphere depends on the efficiency of its conversion. Carbon capture and storage (CCS) may be feasible for large centralized production and could potentially result in negative carbon dioxide emissions from the use of energy commodities.

Based on the marginal efficiency of each method, electrolysis can be considered the most promising method for extracting large-tonnage low-carbon hydrogen, as this method stands out as the most effective in obtaining the purest product at the final stage. Leading global companies like: Siemens, GE, Sunfire, ITM Power chose the vector for scaling up technologies and increasing electrolysis plants up to 2–5 MW. At the moment, electrolyzers with a total total capacity of only 0.2 GW are operating all over the world.

The liquefaction of hydrogen significantly increases its specific energy, which makes it possible to transport it in large volumes by road tanker or ship, which is especially attractive for long distances where pipelines are not economically feasible. More than 90% of commercial hydrogen is transported to the US in liquid form, demonstrating the maturity of liquefaction technology.

Liquefaction consumes significantly more energy than compression. The 2020 US target for large-scale liquefaction energy consumption is 11 kWh/ kg hydrogen, with the potential to be reduced to 6 kWh/ kg in the long term. All large scale hydrogen liquefaction plants are based on the Claude pre-cooling system. 11 kWh is one third of the stored energy in a kilogram of fuel, so if electricity is used at 50% efficiency, liquefaction adds 0.66 units of primary energy consumed per unit of hydrogen delivered.

Transportation of hydrogen. In practice, three variants of hydrogen distribution are used, the suitability of which depends on the volume of demand and the distance of transportation. Transportation of compressed hydrogen using pipe trailers will help in the initial phase of infrastructure development, while pipelines are better suited for mass use. Pipelines can provide scalability if heating, electricity and industry are converted to hydrogen. Liquefaction can be used for international transport of hydrogen in bulk.

Pipelines are considered the most efficient way to transport large amounts of hydrogen over short distances. Some 5,000 km of high-pressure hydrogen pipelines are already in use in Europe and North America for industrial processes. However, high costs prevent further development of pipelines until a stable and significant demand for hydrogen is ensured.

Low initial usage and high initial costs are likely to hinder infrastructure development. Existing high carbon steel natural gas pipelines can fail if repurposed due to hydrogen embrittlement, so new high quality steel construction will be required. Embrittlement is not a concern at lower pressures and the new PE natural gas pipes being installed in the UK and Europe are compatible with hydrogen. These polyethylene pipes are currently limited to 7 bar, but larger plastic pipes up to 17 bar have been proposed. Hydrogen pipelines have a long service life (50–100 years), although the degree of embrittlement of steel pipelines can make prediction difficult [Making the Hydrogen... 2021].

Hydrogen storage. Large-scale hydrogen storage is one of the few low- carbon solutions to balance long-term disruptions in wind and solar power generation, especially due to off-season shifts. As with compressed air energy storage (CAES), hydrogen can be stored in compressed form in underground storage facilities. Hydrogen offers an energy density of 280 kWh, which is 100 times greater than compressed air. There are suitable gas storage facilities in a limited number of regions. Operational projects include 24 GWh capacity in the UK and an 83 GWh plant in Texas. Hydrogen is currently the only low-carbon technology capable of storing more than 100 GWh and operating for weeks or even months, although this is countered by poor distribution efficiency and high equipment costs.

However, due to capacity constraints, a significant amount of decentralized high-pressure storage is required for transportation, especially at filling stations and on board vehicles.

Currently number of alternative hydrogen carriers with a lower level of technological readiness are being considered. Solid carriers, including metal hydrides, are already used in several niches, including submarines and scooters. They operate at low pressure and therefore require fewer safety restrictions than highly compressed or liquefied hydrogen, making them attractive for use in densely populated areas. Their gravimetric energy density (about 3% hydrogen by weight) is comparable to compressed gas at 500 bar. Borohydrides are a promising option that can potentially store more than 10% by weight. Hydrides have cheaper system components (eg. small compressor, blower heater) than compressed or liquefied hydrogen storage. Slow charge and discharge rates limit their suitability for onboard applications, meaning that hydrogen must be separated from hydrides at filling stations and compressed for onboard storage.

According to the analysis of the strategic documents of the Russian Federation in the field of hydrogen energy, it can be concluded that an export-oriented vector of energy development has been chosen. It should be noted that the export concerns resources and the main commodity will be hydrogen and its derivatives.

Achievement of the set export targets will require the development of infrastructure for the production and transportation of this commodity. Russia has large reserves of natural gas, therefore in order to quickly launch hydrogen production, it will be necessary to develop or establish a transfer of technologies for the production of fuel by steam reforming. However, potential importers demand a minimum carbon footprint for goods, including energy resources. Which leads to the need to deploy CCS technologies.

In the future by 2030 European importers will require the supply of exclusively "green" hydrogen. Large-scale production of carbon -free hydrogen will require the development of electrolysis technologies. However, today in Russia there are no technologies that allow the production of high-capacity plants (2-5 MW). According to the analysis of the state of technology in Russia, it is necessary to implement the following tools to start developing the production of electrolyzers:

1. Increasing funding for R&D aimed at developing electrolysis plants based on proto-exchange membranes of high and medium power.
2. Localization of production of electrolysis plants.

3. Stimulation of the development of materials science in the field of electrolysis (polymers, electrolytes, catalysts).

Export deliveries of hydrogen will require the development of hydrogen transportation technologies. Russia has a developed pipeline infrastructure. It should be noted that some of the pipelines are outdated and the use of hydrogen can cause premature aging of the material with further destruction. However, according to experts Nord Stream 2 can be used to transport methane -hydrogen mixtures with a mass hydrogen content of up to 20%. However, when exporting to the Asia-Pacific region, it will be necessary to develop technologies for large-tonnage sea transportation of hydrogen or its derivatives (ammonia, methanol).

Ensuring reliable supplies, which will not be affected by possible equipment failures will require the formation of strategic reserves of hydrogen. Geological voids or salt mines can be a key method for storing hydrogen. To ensure the necessary reserves it is necessary to carry out additional geological surveys and exploration of additional places for hydrogen storage. In addition to mapping potential suitable gas storage facilities the development of new or adaptation of existing gas pumping equipment will be required.

The introduction of hydrogen technologies in the energy sector should begin with the development and development of gas turbines for hydrogen and methane -hydrogen mixtures. To date JSC Power Machines has begun developing its own hydrogen-fuelled units.

According to the fundamental documents for the development of hydrogen energy in the Russian Federation, the development of the export potential of Russian hydrogen is a priority. However, the priority for the EU is the development and supply of "green" hydrogen, produced using mainly wind and solar energy. Renewable hydrogen is the most compatible option with the EU climate agenda and the goal of zero pollution in the long term, and the most aligned with the integrated energy system. On the way to 2050, the production of "green" hydrogen should gradually increase in production and consumption along with an increase in renewable energy capacity [Nizkouglerodnyy vodorod... 2022].

Carbon hydrogen is needed in the short to medium term, primarily to rapidly reduce emissions from existing hydrogen production technologies.

The hydrogen ecosystem in Russia will develop along a gradual trajectory, at different speeds in different sectors and possibly in different regions, and requires different policy decisions.

In the first phase, from 2021 to 2024, the strategic goal is to produce and export 200 kt of low-carbon hydrogen decarbonize existing hydrogen production, for example in the chemical sector, and facilitate hydrogen consumption in new end-use applications such as industrial processes and, possibly in heavy vehicles [A hydrogen strategy... 2020].

On this stage, it is necessary to expand the production of electrolyzers, including large ones. These cells can be installed close to existing demand centers in large refineries, steel mills and chemical plants. Ideally, they should be powered directly from local renewable electricity sources. In addition, hydrogen filling stations will be needed to refuel hydrogen fuel cell buses and, at a later stage, trucks. The electrolyzers will also be needed to supply a growing number of hydrogen filling stations locally. Various forms of electricity-based low- carbon hydrogen, especially those produced with near-zero greenhouse gas emissions, will help expand production and increase the market for hydrogen. Some of the existing hydrogen production plants need to be decarbonized through modernization and provision with carbon capture and storage technologies [ibid].

Hydrogen transport infrastructure needs will remain limited as demand will initially be met by local or local production, and blending with natural gas may occur in some areas, but planning for medium and long-haul transport infrastructure should begin. Infrastructure to capture carbon and use carbon dioxide will be required to facilitate some forms of low-carbon hydrogen.

The main attention will be paid to the creation of a regulatory framework for the liquid and gaseous hydrogen market, the development of technologies, as well as the creation of a national standards base. Favorable framework conditions will push the development of large wind and solar power plants designed to produce renewable hydrogen on a gigawatt scale until 2030.

On this stage of the development of hydrogen energy, attention should be paid to the implementation of pilot projects for the entire supply chain of hydrogen energy. For the large-scale development of technologies, it is necessary to pay special attention to the transfer and localization of the production of high-tech and innovative equipment for hydrogen energy.

On the second stage from 2024 to 2030 hydrogen should become an integral part of the integrated energy system with the strategic goal of supplying at least 2 million tons of hydrogen produced by steam reforming and using electric energy based on renewable energy sources.

On this stage renewable hydrogen is expected to gradually become cost-competitive with other forms of hydrogen production, but industrial demand will require dedicated demand policies to gradually include new uses, including steel production, trucks, rail and some forms of maritime transport. and other modes of transport. Renewable hydrogen will begin to play a role in balancing the renewable energy system by converting electricity to hydrogen, and it is also planned to use hydrogen for daily or seasonal storage to ensure uninterrupted supply [Nizkouglerodnyy vodorod... 2022].

In addition, further upgrades to existing conventional fuel-based hydrogen production using carbon capture technologies should lead to reductions in emissions of greenhouse gases and other air pollutants, given the increased climate ambitions for 2030.

On this stage there will be a need to create a logistics infrastructure, and steps will be taken to transport hydrogen from areas with great renewable energy potential to demand centers. It will be necessary to plan the basis of the all-Russian network and the creation of a network of hydrogen filling stations. The existing gas network could be partly repurposed to transport renewable hydrogen over long distances, and larger hydrogen storage facilities would need to be developed. International trade can also develop, in particular with neighboring countries in Eastern Europe and in the countries of the Southern and Eastern Mediterranean, as well as the Asia-Pacific region [A hydrogen strategy... 2020].

The key feature of this stage is the large-scale production of hydrogen technologies that were developed at the previous stage. The possibility of replicating proven technologies and scaling the obtained scientific and technical reserve to the international level should be provided.

In the third phase from 2030 to 2050 renewable hydrogen technologies must mature and be deployed on a large scale to cover all hard-to-decarbonize sectors where other alternatives may not be feasible or have higher costs.

At this point, renewable electricity production should increase significantly, as by 2050 about a quarter of renewable electricity could be used to produce green hydrogen.

In particular, hydrogen and hydrogen-derived synthetic fuels can seep into a wider range of economic sectors, from aviation and shipping to hard-to- decarbonize industrial and commercial buildings.

Based on analytical reports from reputable international energy organizations such as the IEA (International Energy Agency) and IRENA (International Renewable Energy Agency), it can be concluded that clean hydrogen will play a critical role in the energy transition. If the world wants to achieve the Paris Agreement and zero emissions by 2050, solar and wind power will not be enough. There is a need to reduce carbon emissions in areas such as manufacturing and heavy and long haul transportation, while we can store energy for several months with low levels of solar and wind energy production. This is where biogas can help, but it faces severe volume limitations. One of the few scalable solutions is pure hydrogen produced from renewable or nuclear energy or fossil fuels with carbon capture and storage (CCS)[1].

The recent launch of Japan's first liquefied hydrogen carrier vessel is a historic event that has been widely publicized in the media. Like the first LNG tanker more than half a century ago, it marks the beginning of a new era. Once again, Japan is leading the way in establishing the first international trade routes to bring clean hydrogen from Australia and Brunei to Japan[2].

The analysis of promising sales markets for energy hydrogen was carried out on the basis of data obtained from open sources on the Internet.

1 Mezhdunarodnoye agentstvo vozobnovlyayemoy energetiki (IRENA) [International Renewable Energy Agency (IRENA)]. *Assotsiatsiya "NP Sovet rynka"*: website. Available at https://www.np-sr.ru/ru/organizacii-informacionnogo-fonda/mezhdunarodnoe-agentstvo-vozobnovlyaemoy-energetiki-irena (accessed 08/12/2022).

2 Yaponiya spustila na vodu pervyy v mire tanker po perevozke zhidkogo vodoroda [Japan launches world's first liquid hydrogen tanker] // NGVrus : вэбсайт. Available at https://ngvrus.ru/news/2019/12/11/yaponiya-spustila-na-vodu-pervyy-v-mire-tanker-po-perevozke-zhidkogo-vodoroda.html (accessed 08/12/2022).

During the analysis, hydrogen importing countries for 2019 were identified. The United States is in first place in terms of hydrogen imports in 2019. The import volume amounted to 57.9 million US dollars, which is 34.2% of the total hydrogen import volume. The import volume of hydrogen in Belgium for 2019 amounted to 52.7 million US dollars, which is 31.1% of the total import volume for all countries. France ranks third in the ranking of hydrogen importers for 2019. The import volume of this country amounted to 13.4 million US dollars, which is approximately 8% of the import volume for all hydrogen importing countries. Next are: the Netherlands – $8.7 million (5.1% of total imports in 2019); Germany – $8.3 million (4.8% of total imports in 2019); Canada – $4.1 million (2.4% of total imports in 2019); Luxembourg – $2.8 million (1.6% of total imports in 2019); Mexico – $2.6 million (1.5% of total imports in 2019) [10].

In order to determine the potential for the development of the hydrogen economy in the Russian Federation, as part of the study, work was carried out to rank sales markets. For ranking purposes, countries with significant imports of hydrogen or significant imports of energy commodities were selected. From the number of importing countries, those that have a high degree of specificity of trade and economic relations, as well as those countries whose geographical location makes it difficult to import hydrogen, were excluded. In total, 75 importing countries were analyzed, among which 15 most promising importers of energy hydrogen were identified.

The rating of hydrogen sales markets was calculated as an average value for 7 criteria, each of which was assigned an expert assessment from 0 to 5. Thus the maximum possible rating is 5, the minimum is 0.

In order to rank hydrogen sales markets, the following criteria were formed:

- Assessment of the main economic characteristics of the country; (GDP growth)

The score for the criterion "assessment of the main economic characteristics" was calculated on the basis of the following economic indicators of countries: GNP, GDP, economic growth rate, national income.

- Assessment of the sales market capacity (import);
- Estimation of sales market growth rates;
- Demand assessment for hydrogen;
- Assessment of remoteness and logistics costs;

This estimate was calculated based on the country's territorial proximity to the Russian Federation. Thus 5 groups were identified. Countries that are closest to Russia or have the most favorable logistical conditions – 5, countries that are located the furthest from Russia or have the most problematic locations for logistics – 1. In this regard, the points were ranked as follows (Table 1):

- 5 points – countries that have a common land border with Russia;
- 4 points – countries with a sea or land distance from the Russian Federation from 3 to 6 thousand km;
- 3 points – countries with a sea or land distance from the Russian Federation from 6 to 10 thousand km;
- 2 points – countries with a sea or land distance from the Russian Federation from 10 to 14 thousand km;
- 1 point – countries with a sea or land distance from the Russian Federation from 14 thousand km. and more.

- Assessment of the level of competition in the sales market;
- Assessment of consumer loyalty [Hydrogen, rare gases... n. d./2022].

Table 1. **Ranking of hydrogen sales markets**

Countries/ evaluation criteria	Assessment of the main economic characteristics of the country	Sales market capacity assessment	Estimation of sales market growth rates	Hydrogen Demand Estimation	Estimation of remoteness and logistics costs	Assessment of the level of competition in the sales market	Consumer loyalty assessment	Final grade
Germany	5	5	5	5	4	5	5	**4.86**
Japan	5	5	5	5	4	4	5	**4.71**
South Korea	5	5	5	5	4	3	5	**4.57**
Netherlands	5	4	4	5	4	4	5	**4.43**

Countries/ evaluation criteria	Assessment of the main economic characteristics of the country	Sales market capacity assessment	Estimation of sales market growth rates	Hydrogen Demand Estimation	Estimation of remoteness and logistics costs	Assessment of the level of competition in the sales market	Consumer loyalty assessment	Final grade
France	5	5	4	5	4	3	4	**4.29**
China	5	4	5	4	5	4	2	**4.14**
Belgium	4	5	4	4	4	2	5	**4.00**
Austria	4	4	4	3	4	3	5	**3.86**
Great Britain	4	4	4	4	4	3	4	**3.86**
Italy	3	4	4		4	4	4	**3.86**
Denmark	4	3	4	3	4	2	5	**3.57**
Switzerland	4	3	4	3	4	1	5	**3.43**
Czech	3	4	3	3	4	2	3	**3.14**
Poland	3	3	3	3	5	1	2	**2.86**
Israel	3	3	3	3	3	1	2	**2.57**

Source 10. *Source: Compiled by the author from the official OEC [Hydrogen, rare gases... n. d./2022]*

The analysis of the sales markets for energy hydrogen showed that Germany is the most promising country for the sale of hydrogen. The average score for this market is 4.86 points out of 5 possible. The second line of the rating is occupied by Japan with an average score of 4.71 out of 5. According to expert estimates, the level of competition in the Japanese market is slightly lower than in Germany. By all other criteria, Japan is not inferior to the first number of the list. South Korea ranked third with an average score of 4.57. According to expert assessment, the level of competition in the Korean market is average, with an indicator of 3 points. In this regard, South Korea is on the third line of the rating. The following is a ranked list of the most promising markets for hydrogen sales: Germany, Japan, South Korea, Netherlands, France, China, Belgium, Austria, Great Britain, Italy, Denmark, Switzerland, Czech, Poland, Israel.

According to the Energy Strategy of the Russian Federation, for the period up to 2035, approved by the Decree of the Government of the Russian Federation dated June 9, 2020 No. 1523-r, the target indicators for the export of energy hydrogen are set: by 2024 – 0.2 million tons; by 2035 – 2 million tons [Energy Strategy... 2020].

The concept for the development of hydrogen energy in the Russian Federation, approved by the Decree of the Government of the Russian Federation of August 5, 2021 No. 2162-r, sets the potential volume of exports of energy hydrogen at the level of: by 2024 – 0.2 million tons, by 2035 – 2-12 million tons, by 2050 – 15-50 million tons [Kontseptsiya... 2021].

Conclusion

Today, the climate agenda is one of the most important and discussed topics. The fundamental document is the Paris Agreement, the main goal of which is to reduce carbon dioxide emissions to the level of 1990. To achieve this goal, hydrogen was chosen as the main energy carrier.

Hydrogen energy located on the stage becoming that opens wide capabilities for development and formation new high-tech productions and chains added cost, in volume number, international, and also for formation new directions export. By some expert estimated by 2050 the capacity hydrogen market may reach 2.5 trillion dollars USA, displacing 20% of fossils energy carriers from world economy. Potential market niche Russian Federation on this market 10% is estimated.

Many countries already approved strategies development hydrogen energy. Among them Germany, Canada, France, Japan, USA and South Korea. AT June 2020 government Germany published National hydrogen strategy. Also many German companies carry out work on creation pilot projects aimed on the receiving pure hydrogen and burial carbon dioxide gas. For example, Uniper and General Electric («GE») signed in June 2020 an agreement directed on the long-term cooperation in areas decarbonization gas power plants and vaults natural gas Uniper. GE Gas Power and Uniper will study, evaluate and develop technological options decarbonization. Agreement sent on the development detailed road cards decarbonization to early 2021.

The Russian Federation has significant opportunities for the production of hydrogen, its use in the energy sector and industry, having a number of competitive advantages and a serious potential in the field of hydrogen energy. Competitive advantages are expressed by proximity to potential sales markets (EU countries and the Asia-Pacific region), the availability of raw materials (gas, coal, electricity) and production capacity reserves. In turn, the potential lies in the existing scientific and technical reserve of domestic enterprises, formed in the Soviet and post-Soviet period [Chernikov 2016].

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Information about the authors:

Kalmykov Aleksey S. and **Vasiliev Artem S.** – post-graduate students; **Sokolan Daria S.** — Candidate of Economic Sciences, Assistant of the Department of International Economic Relations. Author ID(RCSI): 1086830.

Place of work of the authors: Peoples' Friendship University of Russia (RUDN University), 6 Miklukho-Maklaya st., Moscow 117198, Russia.

Информация об авторах:

Калмыков Алексей Сергеевич и **Васильев Артем Сергеевич** — аспиранты; **Соколан Дарья Сергеевна** — кандидат экономических наук, ассистент кафедры МЭО. Author ID(РИНЦ): 1086830.

Место работы авторов: Российский университет дружбы народов (РУДН), ул. Миклухо-Маклая 6, Москва 117198, Россия.

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