Biofuel as a renewable energy resource

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Abstract. The article considers biofuels as one of the promising areas for the development of renewable energy in the context of depletion of fossil fuel reserves, tightening environmental requirements and the need to improve the sustainability of energy systems. An analysis of the main types of biofuels, their raw material base and technological features of production is carried out. Particular attention is paid to assessing the renewability of biofuels and their potential for reducing greenhouse gas emissions due to the formation of a relatively closed carbon cycle. The key advantages and limitations of biofuel use are summarized, taking into account economic, environmental and resource factors. Separately, the prospects for the development of second- and third-generation biofuels as the most technologically and environmentally efficient areas are considered. Along with this, the article analyzes the current state of the oil and gas industry, which continues to be one of the priority sectors of the national economy. The main problems and trends of its development, production dynamics, resource availability, as well as the role of domestic and foreign research and development are considered. The contribution of the biofuel complex to the development of the national economy, prospects for investment activity and ways to optimize the use of hydrocarbon resources are considered. The article presents data on the dynamics of foreign direct and financial investment and forecasts of the indicator, which allows for a comparison of traditional and alternative energy directions in the context of long-term energy development.

INTRODUCTION

The current development of the global energy sector is characterized by a simultaneous increase in energy consumption, depletion of fossil fuel reserves, and increasing environmental constraints associated with climate change and environmental degradation. Under these conditions, the search for and implementation of alternative, environmentally friendly, and renewable energy sources is becoming a priority for sustainable socioeconomic development. Biofuels occupy a special place among renewable energy resources, as they have the potential to partially replace traditional hydrocarbon fuels and can be produced from a wide range of biological raw materials, including agricultural crops, agro-industrial waste, and organic waste. The use of biofuels helps reduce anthropogenic impacts on the environment, reduce greenhouse gas emissions, and improve energy security. At the same time, the traditional oil and gas industry continues to play a key role in the economies of most countries, providing a significant share of the energy balance, export revenues, and investment activity. This necessitates a comprehensive analysis of the interactions and comparisons of traditional and alternative energy sources, as well as an assessment of the prospects for their joint development in the context of the energy transition. The aim of this work is to analyze biofuels as a renewable energy resource, assess its economic and environmental potential, and consider the main directions of development of biofuel technologies in the context of the current state and prospects of the oil and gas sector.

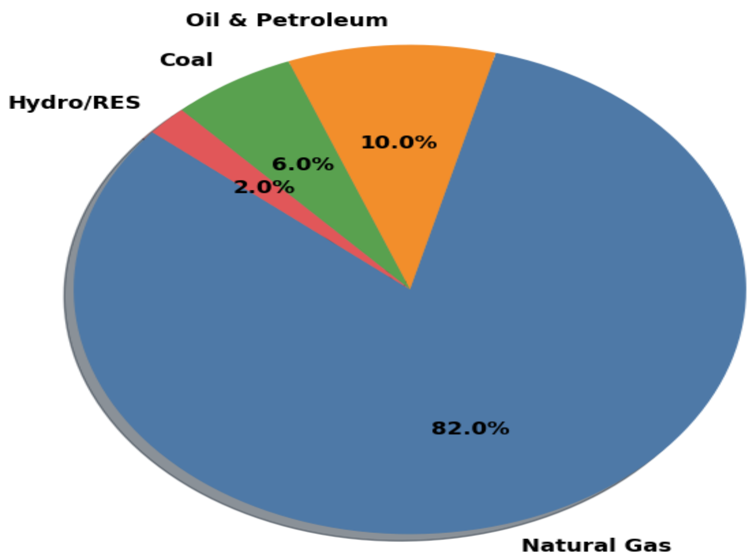

Fig.1. Shares of Energy Resources in Uzbekistan Energgy Consumption (2023)

Methods and Experimental Design. Biofuel formulations were developed using various types of plant-based feedstocks, yielding both solid granulated fuel and liquid biodiesel. Plant residues from oilseed processing, specifically rapeseed cake husks, seed coats, and similar highly organic materials, were used as the base for the granulated biofuel. The feedstock was pre-processed mechanically, crushed to an optimal fraction and dried to a moisture content ensuring stable granulation. This approach not only increases the density and homogeneity of the granules but also improves their calorific value and performance during storage and combustion. From a scientific perspective, the use of plant residues allows for the rationalization of resources, reducing agricultural waste and implementing circular economy principles. Waste vegetable oils, including sunflower, rapeseed, and soybean oils from food use, were used to produce liquid biofuel (biodiesel). The chemical transformation of the oil was carried out by the transesterification method, using a low molecular weight alcohol (methanol or ethanol) as a reagent and an alkaline catalyst (potassium hydroxide KOH or sodium hydroxide NaOH).

For products with elevated free fatty acid content, pre-treatment with sulfuric acid was performed to reduce the acid value and prevent side reactions such as soap formation. The transesterification process was conducted at a controlled temperature of 50-60°C with vigorous stirring for 60-90 minutes, ensuring uniform interaction of the components and accelerating the chemical reaction. After the reaction was complete, the mixture was allowed to separate phases, with the upper phase representing the biofuel and the lower phase representing technical glycerin. The resulting biofuel product underwent multi-stage washing with distilled water to remove residual catalyst and impurities, followed by drying to remove moisture and quality assessment based on density, homogeneity, and product yield.

Biodiesel purification was performed by repeated washing with distilled water, followed by drying to remove moisture and catalyst residues. Product quality was assessed based on density, visual homogeneity, and yield, allowing for quantitative evaluation of the effectiveness of the selected formulation.

The scientific significance of formula development lies in the integrated approach to the use of renewable and recycled raw materials, optimization of process parameters, and quality control of the final product. The experimental phase involved varying the ratios of feedstock, alcohol, and catalyst, as well as reaction time and temperature, allowing us to determine the optimal conditions for producing biofuel with maximum yield and consistent performance characteristics. All data was systematically recorded, ensuring the reproducibility of the experiments and the possibility of further analytical processing. This approach provides a comprehensive scientific and practical assessment of biofuel production methods in both solid granular and liquid forms, confirming their effectiveness and environmental friendliness.

Before chemical processing, the feedstock underwent preliminary preparation, including purification from mechanical impurities and filtration. When necessary, dehydration was performed to remove excess moisture by heating to 100°C. At the same time, the content of free fatty acids was determined, which made it possible to select the optimal method of processing raw materials - alkaline or acidic - in order to increase the yield of biofuel and reduce the formation of by-products.

Chemical conversion of the oil feedstock was accomplished via transesterification using a low-molecular-weight alcohol (methanol) as the alcohol component and an alkaline catalyst—potassium hydroxide (KOH) or sodium hydroxide (NaOH). When the free fatty acid content was high, pre-treatment with sulfuric acid was used to neutralize the acids and prevent soap formation. Distilled water was used for subsequent purification and washing of the biofuel, ensuring a neutral pH and the removal of catalyst residues and reaction byproducts.

Recipe development was accomplished by varying the ratios of oil feedstock, alcohol, and catalyst to optimize yield and ensure consistent biofuel performance. Each experiment was documented, recording the component masses, reaction temperature, reaction time, and volume of biofuel produced. The research resulted in a formulation that ensures maximum yield and high-quality liquid biofuel obtained from waste vegetable oils, confirming the effectiveness of the method used and its scientific validity. Rapid global population growth is leading to increased demand for various resources, including electricity. Industrial development, urbanization, and rising living standards are further increasing the burden on the electricity sector [1].

One promising area for the biofuel industry is the use of waste from the oil and fat industry, particularly oil mill waste, as feedstock for the production of biofuels and biodiesel. Such waste includes waste vegetable oils, fatty residues, and industrial fats, which can account for up to 10-15% of the total volume of processed feedstock. Using oilseed waste can reduce the cost of biodiesel production by 30-50% compared to using virgin vegetable oils. The yield of biodiesel from processing waste vegetable oils reaches 85-95% of the feedstock, making this process technologically and economically efficient. Biodiesel, produced from oil mill waste, has a calorific value of 37-40 MJ/kg, which is only 8-12% lower than traditional petroleum diesel fuel. Furthermore, its use reduces carbon dioxide emissions by an average of 50-70% over the fuel's life cycle, and produces virtually no sulfur emissions.

This makes it possible and feasible, under certain conditions, to combine them into a single enterprise—a biodiesel plant. Each production facility within the biodiesel plant specializes in the production of specific products and has a specific technological process. In turn, the consolidation of several production facilities into a single enterprise leads to a concentration of production, as the enterprises are consolidated. The economic benefits of specialization are fully preserved and are complemented by the cost savings resulting from the consolidation of several facilities. The use of chemical and biochemical methods in production leads to the most efficient processing schemes for raw materials, allowing for the maximum extraction of useful substances. Low-value food industry waste, thanks to chemical processing methods, becomes suitable for the production of many valuable products.

Husk, a waste product of the oil and fat industry, is chemically processed and used to produce fodder yeast. Furfural, fodder yeast, xylitol, and other products are obtained from cottonseed husks when chemically treated.

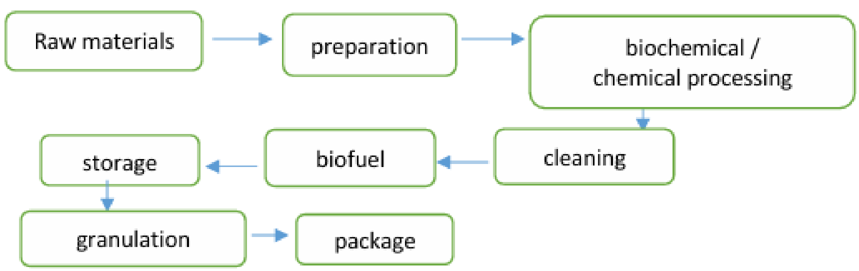

Fig2. Technological scheme of biofuel production

A characteristic of processing raw materials with a complex physicochemical composition is the formation of a significant volume of byproducts and waste, which is typical for food industries, including sugar, alcohol, wine, canning, and starch processing. For example, when processing seeds in the oil and fat industry, traditional methods extract only the fat, while the proteins contained in the seeds in large quantities remain in the cake and meal. These byproducts and waste can be used as raw materials for further processing and the production of additional valuable products. The process of producing biofuel from composted granular feedstock begins with the preparation of the feedstock, which includes cleaning, screening, and moisture equalization of granulated waste from the oil and fat and food industries to ensure the homogeneity of the final product. The feedstock then undergoes grinding and conditioning, which produces the optimal fraction and prepares it for pressing, ensuring high strength and uniformity of the pellets.

The feedstock is then pressed or granulated, resulting in dense and uniform biofuel granules with controlled physical and mechanical properties. The formed granules are dried and cooled to reduce moisture content to ≤10% and stabilize the product, which improves its durability and calorific value. The finished biofuel is then packaged and stored in dry conditions until use. Using this biofuel in boilers, furnaces, and power plants ensures highly efficient thermal energy production and significantly reduces greenhouse gas emissions compared to traditional hydrocarbon fuels.

Thus, this technological process demonstrates a comprehensive approach to converting organic waste into an environmentally friendly and energy-efficient product, combining economic feasibility with sustainable energy development. The production and use of biofuels are characterized by lower total greenhouse gas emissions compared to traditional fossil fuels. This is because the carbon released during its combustion enters the short-term biogenic cycle and was previously assimilated by plants through photosynthesis. According to life cycle assessments, the use of biofuels reduces CO_2 emissions by 40-60% for bioethanol from grain feedstock and up to 80% for biogas and biodiesel produced from biomass waste, thereby reducing anthropogenic impact on the climate. Biofuels are produced from renewable resources, reducing the energy sector's dependence on non-renewable oil, gas, and coal. Using agricultural and organic waste as feedstock aligns with the principles of a circular economy, reducing waste and minimizing pollution of soils and aquatic ecosystems.

However, expanding the area under energy crops can negatively impact land resources and biodiversity, causing soil degradation and the transformation of natural ecosystems. These risks are mitigated by using recycled resources, low-productivity land, and the introduction of perennial energy crops with high productivity and reduced need for agrochemicals.

Biofuel combustion results in lower emissions of sulfur-containing compounds, particulate matter, and toxic organic matter, improving air quality and reducing sanitary and hygienic risks. However, if process conditions are not met, methane leaks, which have a high greenhouse potential, are possible, requiring strict monitoring of process equipment. By-products of biofuel production, when processed efficiently, are used as fertilizers, secondary raw materials, and feed additives, increasing the resource efficiency of the process.

Biofuel was produced from secondary oilseed feedstock by processing agricultural and food processing byproducts, such as oilcake, husks, and other residues from vegetable oil extraction. These secondary feedstocks are characterized by a high organic matter content and sufficient calorific value, making them promising for use as solid biofuel. To increase density, improve physical and mechanical properties, and facilitate transportation and storage, the feedstock was briquette-formed. Before briquetting, the secondary oilseed feedstock was pre-crushed and dried to an optimal moisture content, ensuring the formation of strong and uniform fuel briquettes. The briquetting process was carried out under elevated pressure, which compacted the biomass and partially bound the particles using the natural binding components contained in the plant feedstock. The resulting briquettes had a high bulk density, stable geometric shape, and improved performance characteristics. The figure shows samples of biofuel obtained by briquetting.

a) b)

Fig3. The appearance of fuel briquettes made from waste; a) briquettes made from waste from oilseed processing; b) from leaves and other waste

The resulting briquetted biofuel is characterized by increased calorific value, low sulfur content, and reduced emissions during combustion compared to traditional fossil fuels. Using secondary oilseed feedstock to produce briquetted biofuel reduces agricultural waste, lowers the environmental impact, and improves resource efficiency in the agro-industrial complex. Thus, briquetted biofuel from secondary oilseed feedstock is an environmentally and economically viable renewable fuel suitable for use in power plants for a variety of applications. The resulting briquetted biofuel from secondary raw materials of oilseed crops with an optimal moisture content of 6–9% is characterized by a high density (950–1200 kg/m³) and a calorific value of 16-19 MJ/kg, which confirms its energy efficiency and the feasibility of use as a renewable fuel.

Overall, the environmental sustainability of biofuel production is determined by the entire process chain. With the use of best available technologies and comprehensive environmental monitoring, biofuels are an environmentally sound option and contribute to the sustainable development of the energy sector.

CONCLUSIONS

Biofuel production is a promising area of energy development, combining environmental and economic advantages. The use of renewable raw materials, including agricultural and organic waste, reduces waste disposal costs and partially replaces imported fossil fuels, thereby increasing energy security and economic sustainability. The economic efficiency of biofuels is determined by a combination of factors, including the availability and cost of raw materials, the level of technological equipment at the production site, and the degree of by-product processing. Of significant importance is the ability to utilize raw materials comprehensively, with by-products (digestate, glycerin, and stillage) being sold as marketable products or used internally, reducing the cost of the primary fuel and increasing overall production profitability. An additional economic benefit is the reduction in costs associated with negative environmental impacts, including lower fees for pollutant and greenhouse gas emissions, and the mitigation of environmental risks. With government support, tax incentives, and carbon regulation mechanisms, biofuels are becoming competitive with traditional fuels. Thus, with the implementation of best available technologies and a rationally organized production process, biofuel production is economically feasible. The resulting product has sustainable market potential, contributes to the diversification of the energy balance, and ensures a positive economic outcome through reduced costs, additional monetization of by-products, and long-term environmental benefits. The research resulted in the production of briquetted biofuel from secondary oilseed feedstock, characterized by satisfactory physical, mechanical, and energy properties. Optimization of moisture content and briquetting parameters increased the density and calorific value of the fuel, as well as improved its performance during storage, transportation, and combustion. Using oilseed husks and cake as feedstock for the production of briquetted biofuel is environmentally and economically feasible, as it helps reduce agricultural waste, mitigate environmental impacts, and promote the rational use of renewable resources. The resulting biofuel can be considered a promising alternative to traditional solid fuels and is recommended for practical use in power plants for various applications.

REFERENCES

1. A. Demirbas, *Biofuels: Meeting the Planet's Future Energy Needs* (Springer, London, 2009).
2. P. McKendry, "Biomass energy production (Parts 1–3)," *Bioresour. Technol.* **83**, 37–67 (2002).
3. International Energy Agency (IEA), *Bioenergy: A Sustainable and Reliable Source of Energy* (IEA, Paris, 2009).
4. Intergovernmental Panel on Climate Change (IPCC), *Renewable Energy and Climate Change Mitigation* (Cambridge University Press, Cambridge, 2011).
5. J. Hill, E. Nelson, D. Tilman *et al.*, "Environmental, economic, and energy costs and benefits of biodiesel and ethanol biofuels," *Proc. Natl. Acad. Sci. U.S.A.* **103**, 11206–11210 (2006).
6. J. Goldemberg, "Ethanol for a sustainable energy future," *Science* **315**, 808–810 (2007).
7. F. Cherubini and A. H. Strømman, "Life cycle assessment of bioenergy systems," *Energy* **36**, 1097–1106 (2011).
8. Food and Agriculture Organization (FAO), *The State of Food and Agriculture: Biofuels – Prospects, Risks and Opportunities* (FAO, Rome, 2008).
9. S. N. Naik, V. V. Goud, P. K. Rout, and A. K. Dalai, "Production of first- and second-generation biofuels," *Renew. Sustain. Energy Rev.* **14**, 578–597 (2010).
10. M. Balat and H. Balat, "Recent trends in global production and utilization of bio-ethanol fuel," *Appl. Energy* **86**, 2273–2282 (2009).
11. V. A. Kochkarov and A. I. Sokolov, *Biofuels and Their Use in Energy* (Energoatomizdat, Moscow, 2016).
12. S. N. Popov and L. V. Ivanova, "Biodiesel production from vegetable oils and waste," *Energy Policy and Technology* **3**, 45–52 (2018).
13. D. V. Morozov and P. A. Kuznetsov, *Biomass Production and Processing Technologies* (BHV-Petersburg, St. Petersburg, 2017).
14. A. V. Egorov and E. A. Smirnova, "Environmental aspects of biofuel use in transport," *TSUEP Bulletin* **4**, 77–85 (2019).

15. Sh. Rakhimov and H. Abdullaev, "Prospects for using biomass for biofuel production in Uzbekistan," *Bull. Natl. Acad. Sci. Uzbek.* **2**, 34–41 (2017).
16. B. Ibragimov and M. Sadykova, "Biodiesel production from vegetable and oilseed waste," *Chemical Industry of Uzbekistan* **3**, 12–20 (2018).
17. A. Norbekov and F. Tursunov, "Study of the properties of granulated biofuel from rapeseed cake," *Energy and Resources of Uzbekistan* **1**, 45–53 (2019).
18. L. Karimova, "Rational use of agricultural waste for biofuel production," *Science and Technology of Uzbekistan* **4**, 58–65 (2020).
19. S. Nabieva and S. Atakhanova, "Modern methods of investment activity in the development of industrial enterprises," *AIP Conf. Proc.* **3331**, 050010 (2025). https://doi.org/10.1063/5.0308119
20. O. Begmullaev, S. Nabieva, and S. Mirsaidova, "Classification of energy efficiency policies and their implementation," *AIP Conf. Proc.* **3331**, 030053 (2025). https://doi.org/10.1063/5.0305929
21. G. Allaeva, G. Yusupkhodjaeva, and K. Mukhitdinova, "Methodology for calculating sustainable development of fuel and energy complex enterprises based on consolidated integral indices," *AIP Conf. Proc.* **3331**, 030006 (2025). https://doi.org/10.1063/5.0308133
22. G. Yusupkhodjaeva, G. Allaeva, and K. Mukhitdinova, "Sustainable development of transport enterprises in the context of the formation of the digital economy," *AIP Conf. Proc.* **3331**, 030087 (2025). https://doi.org/10.1063/5.0306872
23. K. Mukhitdinova, G. Yusupkhodjaeva, and G. Allaeva, "Econometric modeling of investment potential of industrial enterprises," *AIP Conf. Proc.* **3331**, 050026 (2025). https://doi.org/10.1063/5.0308123
24. G. Allaeva, "Main directions of sustainable development of fuel and energy enterprises," *AIP Conf. Proc.* **3152**, 050012 (2024). https://doi.org/10.1063/5.0220851
25. G. Allaeva, "The role of energy security in forming the foundations for sustainable development of fuel and energy complex enterprises," *E3S Web Conf.* **461**, 01061 (2023). https://doi.org/10.1051/e3sconf/202346101061
26. G. Allaeva, "Sustainable development methodology of the fuel-energy complex of the Republic of Uzbekistan," *E3S Web Conf.* **289**, 07033 (2021). https://doi.org/10.1051/e3sconf/202128907033
27. G. Allaeva, "Fiscal instruments of taxation improvement as a factor of sustainable development of enterprises of the fuel and energy sector," *E3S Web Conf.* **216**, 01173 (2020). https://doi.org/10.1051/e3sconf/202021601173
28. G. Allaeva, "Priority directions of development of Uzbekneftegas JSC in the conditions of globalization of the world economy," *E3S Web Conf.* **139**, 01008 (2019). https://doi.org/10.1051/e3sconf/201913901008
29. S. Ibragimova and K. Bakhodirova, "Formation of investment activities of energy enterprises," *E3S Web Conf.* **461**, 01074 (2023). https://doi.org/10.1051/e3sconf/202346101074
30. R. Xusainov and O. Begmullaev, "Problems of ensuring the electricity supply system in Uzbekistan," *AIP Conf. Proc.* **3331**, 030002 (2025). https://doi.org/10.1063/5.0305927
31. R. Xusainov, B. Tillayeva, and N. Sayfutdinova, "Development of ecology and energy in Uzbekistan," *AIP Conf. Proc.* **3331**, 030010 (2025). https://doi.org/10.1063/5.0306384
32. G. Yusupkhodjaeva, "Development of a unified digital transport and logistics intelligent platform based on the national operator," *E3S Web Conf.* **461**, 01055 (2023). https://doi.org/10.1051/e3sconf/202346101055
33. K. Mukhitdinova and G. Tarakhtieva, "Ensuring sustainable future: The interconnectedness of food safety and environmental health," *E3S Web Conf.* **497**, 03037 (2024). https://doi.org/10.1051/e3sconf/202449703037
34. S. Hashimova, D. Yakubova, and N. Tursunova, "Possibilities of expanding the mineral resource as a base of ferrous metallurgy," *Lect. Notes Netw. Syst.* **733**, 879–888 (2024). https://doi.org/10.1007/978-3-031-37978-9_70
35. S. Salomova *et al.*, "Improving the efficiency of energy enterprises," *AIP Conf. Proc.* **3331**, 040076 (2025). https://doi.org/10.1063/5.0305987
36. A. Otabek and O. Begmullaev, "Alternative energy and its place in ensuring the energy balance of the Republic of Uzbekistan," *AIP Conf. Proc.* **2552**, 050030 (2023). https://doi.org/10.1063/5.0117633
37. O. Akhmedov and O. Begmullaev, "Ways of ensuring energy balance in Uzbekistan," *E3S Web Conf.* **216**, 01137 (2020). https://doi.org/10.1051/e3sconf/202021601137
38. S. Salomova, "Increasing the efficiency of oil and gas industry enterprises in Uzbekistan," *AIP Conf. Proc.* **3331**, 040075 (2025). https://doi.org/10.1063/5.0305986
39. K. A. Mukhitdinova and L. A. Vildanova, "Transport improvement of the method of assessing the attractiveness of investment in automotive enterprises," *J. Crit. Rev.* **7**(5), 171–176 (2020). https://doi.org/10.31838/jcr.07.05