Machinery & Energetics
Vol. 16, No. 1. 2025

Journal homepage:
https://technicalscience.com.ua/en

UDC 621.311.22:620.92:633.8
Doi: 10.31548/machinery/1.2025.173

Oleksiy Sadovoy*
PhD in Technical Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-7369-0714

Dmytro Koshkin
PhD in Technical Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0002-6927-8487

Volodymyr Martynenko
PhD in Technical Sciences, Associate Professor
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0000-0003-4067-3640

Vitaliy Sokolik
Master
Mykolaiv National Agrarian University
54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine
https://orcid.org/0009-0006-0264-6333

Electricity generation from biogas: Modern technologies and prospects for Ukraine's energy independence

Abstract. Electricity production from biogas and biomethane is a promising area of renewable energy development that can substantially reduce Ukraine's dependence on fossil fuels, reduce greenhouse gas emissions, and increase energy security. The purpose of the present study was to analyse modern technologies for electricity production from biogas and biomethane, assess their efficiency, technical advantages, disadvantages, and opportunities for integration into the overall energy system of Ukraine. The research methodology included a comparative analysis of cogeneration plants, internal combustion engines, and gas turbines used to generate electricity from biogas, as well as methods of biogas purification to the level of biomethane. The analysis was performed considering technical efficiency, economic feasibility, and environmental safety. The findings of the study revealed that cogeneration units demonstrate the highest efficiency, which ranges from 80-90%, due to the simultaneous production of heat and electricity. Gas turbines provide an efficiency of 30-40%, and internal combustion engines – 25-45%. A comparative analysis of biogas purification methods showed that membrane technologies are the most promising due to their high purification efficiency (95-98%) and economic feasibility. Other methods, such as absorption, cryogenic, and adsorption, have limitations in application due to elevated energy costs or low purification efficiency. It was found that biogas purification to biomethane enables its use for electricity generation, transportation by gas pipelines, and ensuring the stability of power grids, especially during peak load periods.

Article's History: Received: 11.10.2024; Revised: 14.01.2025; Accepted: 27.02.2025.

Suggested Citation:
Sadovoy, O., Koshkin, D., Martynenko, V., & Sokolik, V. (2025). Electricity generation from biogas: Modern technologies and prospects for Ukraine's energy independence. *Machinery & Energetics,* 16(1), 173-185. doi: 10.31548/machinery/1.2025.173.

*Corresponding author

The developed recommendations included improving biogas purification technologies, creating infrastructure for its transportation and storage, and designing mechanisms for government incentives for bioenergy development. The use of bioenergy technologies can ensure the stability of Ukraine's energy system, increase its efficiency, and reduce dependence on conventional energy sources

Keywords: renewable energy; biomethane; cogeneration units; gas turbines; internal combustion engines; gas transmission systems

INTRODUCTION

Electricity production from biogas and biomethane is a promising area of renewable energy development that can greatly reduce Ukraine's dependence on fossil fuels and ensure its energy independence. In the context of growing energy instability and rising costs of conventional energy sources, the use of biogas and biomethane is becoming particularly relevant. Biogas is produced through the anaerobic fermentation of organic materials, which allows converting agricultural, food, and livestock waste into a valuable energy resource. After purification, biogas is converted into biomethane, which can be used as a fuel for generating electricity, heat, or energy storage to stabilise energy networks.

Modern scientific research on the use of biogas for electricity generation shows the immense potential of this technology in the context of energy transformation. Considerable attention has been paid to increasing the efficiency of cogeneration plants by improving combustion processes. O. Kolbasenko *et al*. (2023) demonstrated the possibility of improving heat transfer in power systems through a vibratory combustion mode of a water-fuel emulsion, which reduces fuel consumption and simultaneously increases the overall energy efficiency of plants.

In the field of advanced technologies for generating electricity from biogas, a valuable contribution was made by S.N.K. Syahri *et al.* (2022), who analysed the challenges of converting biogas to electricity using cogeneration technologies. The researchers emphasise the need to improve gas turbines and optimise thermal schemes to increase efficiency. In their global review, B.C.G. Rodrigues *et al.* (2025) outlined the most efficient technologies for anaerobic digestion, multi-stage biogas purification, and standardisation of biomethane production processes, which enables increased stability of generation parameters.

Ł. Mamica *et al.* (2022) analysed the prospects for biogas plants in Poland, focusing on the role of a favourable regulatory framework and investment attractiveness for market expansion. The researchers' conclusions may be relevant to the Ukrainian context, where the issue of incentivising investors and developing infrastructure for biomethane generation and transportation is also relevant. In the same context, it is worth mentioning the study by G. Gadirli *et al.* (2024), which comprehensively overviewed biogas plant technologies and emphasised the significance of biomethane as a tool for stabilising power grids and energy storage. The researchers emphasised the role of gas purification and the development of storage systems to ensure continuity of energy supply.

In terms of biogas purification, the findings of J. Das *et al.* (2022) are notable, as they focused on biological purification methods that reduce costs and improve the environmental safety of the process. The researchers discussed the advantages of biofiltration, photosynthetic, and microbial methods that can be used as an alternative to conventional chemical treatment. In biogas production optimisation, N.I. Madondo *et al.* (2022) compared the efficiency of electromagnetic, microbial, and conventional anaerobic systems. Their findings proved that the use of external electromagnetic fields can increase biogas yields by accelerating methanogenesis, which opened prospects for increasing the productivity of biogas plants.

S. Abanades *et al.* (2022a) conducted an in-depth analysis of global biogas practices, supported by a comparison of legal frameworks in different countries. The study outlined the barriers to technology adoption in countries with low regulatory support and emphasises the need for political will for the successful development of the biogas sector. Special attention should be paid to the study by J. Wang *et al.* (2023), which focused on increasing the efficiency of biogas generation through the pretreatment of agricultural residues, specifically straw. The researchers proved the effectiveness of such methods as steam operation, alkaline activation, and ultrasonic digestion, which improve the bioavailability of raw materials.

A.I. Amhamed *et al.* (2024) analysed the possibilities of using alternative fuels, including biomethane, in the aviation and energy sectors. The modelling showed that biomethane can be successfully integrated into high-temperature generation systems and used in hybrid energy systems that combine cogeneration and energy storage.

Thus, the analysis of scientific sources showed that the development of biogas technologies is focused on three key vectors: gas purification to the level of biomethane, improvement of cogeneration and automated power generation systems, and integration into flexible energy systems with energy storage capabilities. These areas form the scientific basis for enhancing the energy security of countries, including Ukraine, and contribute to strengthening its energy independence in the face of constant external challenges.

The purpose of the present study was to perform a theoretical analysis of existing technologies for electricity production from biogas and biomethane, compare their efficiency, identify shortcomings and prospects for implementation in Ukraine to improve energy security.

MATERIALS AND METHODS

The research methodology included a theoretical analysis of existing technologies for electricity production from biogas and biomethane (Madondo *et al.*, 2022; Wang *et al.*, 2023; Amhamed *et al.*, 2024). The first stage of the study examined the methods of anaerobic digestion of organic materials, such as agricultural, food, and municipal waste. The principal focus was on the conditions under which anaerobic fermentation takes place, including temperature, humidity, pH, microflora composition, and quality of raw materials. Furthermore, the study analysed the technological advancement of converting biogas into electricity using cogeneration units, gas turbines, and internal combustion engines. The influence of technological parameters on the efficiency of electricity generation and the possibilities of their optimisation were recognised. Particular attention was paid to the examination of the efficiency of biogas plants in industrial conditions and the possibility of their improvement.

The second stage of the study was aimed at exploring methods of biogas purification to produce biomethane, which is a high-quality energy carrier that can be used for electricity generation or transportation through gas pipelines. The study considered membrane, absorption, cryogenic, adsorption, and biological purification methods. The analysis was based on their efficiency in removing the major impurities (methane (H_2S), carbon dioxide (CO_2), energy costs, economic feasibility, and the possibility of industrial application in Ukraine. Special attention was paid to the technologies of biogas enrichment to the level of biomethane, including membrane, absorption, cryogenic, and adsorption methods. Their advantages and disadvantages, efficiency in industrial conditions, environmental safety, and economic feasibility were investigated. The possibilities of using purified biomethane to stabilise energy networks and ensure reliable energy supply were also covered.

The third stage of the study involved a comparative analysis of electricity generation technologies from biogas and biomethane. Methods such as cogeneration plants, gas turbines, and internal combustion engines used to convert biogas into electricity are considered. The efficiency of these technologies, their environmental performance, technical advantages and disadvantages, as well as the economic feasibility of their application in various industrial production conditions were assessed in detail. The study employed comparative analysis methods based on the generalisation of data from scientific publications and technical documentation (Mamica *et al.,* 2022; Das *et al.,* 2022; Gadirli *et al.,* 2024). The key indicators of efficiency were as follows: efficiency, emissions of harmful substances, energy costs per unit of treated biogas, specific capital, and operating costs. The assessment was based on a comparison of typical indicators presented by S.N.K. Syahri *et al.* (2022), O. Kolbasenko *et al*. (2023), and B.C.G. Rodrigues *et al.* (2025), as well as generalised data on the practical application of biogas plants in industrial conditions. The research tools included tabular analysis, construction of comparative diagrams, and systematisation of efficiency parameters in the form of analytical ones, which helped to establish optimised technological solutions for the conditions of Ukraine. The study investigated the prospects for the integration of biogas plants into the overall energy system of Ukraine, the possibility of using biomethane for energy storage and stabilisation of power grids, especially in conditions of uneven load and peak consumption periods (Madondo *et al.,* 2022; Abanades *et al.,* 2022a; Amhamed *et al.,* 2024). Possible schemes for the use of biomethane in gas transmission systems, their economic efficiency, and potential ways to increase efficiency by modernising existing technological processes were analysed (Wang *et al.,* 2023).

The final stage of the study focused on the development of theoretical recommendations for improving existing technologies for electricity production from biogas and biomethane. The study considered the possibilities of optimising biogas purification processes, improving electricity generation technologies, and their integration into the Ukrainian energy system. Particular attention was paid to creating conditions for increasing the efficiency of renewable energy sources, improving infrastructure, and developing mechanisms to stimulate the development of bioenergy at the state level.

RESULTS AND DISCUSSION

Analysis of biogas and biomethane production technologies

Biogas is a gas mixture, the principal components of which are CH_4 and CO_2, produced as a result of the anaerobic decomposition of organic matter in specialised plants known as biogas generators or methane tanks. Their design and operation are aimed at maximising methane production. Biogas combustion can recover 60-90% of the energy contained in the original dry feedstock. The biogas production process is based on the anaerobic digestion of organic materials such as agricultural waste, food waste, and municipal waste. The key conditions for anaerobic fermentation include controlled temperature, humidity, pH, microbial composition, and quality of the feedstock. Optimum temperature conditions for anaerobic digestion are divided into mesophilic (30-40°C) and thermophilic (50-60°C). The mesophilic mode requires lower energy consumption, but the fermentation process is slower than in the thermophilic mode. At the same time, thermophilic fermentation ensures faster decomposition of organic matter but requires greater energy consumption and more complex process control.

The moisture content of the feedstock should be maintained at 80-90% to ensure optimum conditions for the microorganisms involved in the fermentation process. The pH value is a critical parameter, as anaerobic microorganisms function best at pH values between 6.5 and 8. The microflora composition includes methanogenic bacteria and enzymatic microorganisms, which ensure a full cycle of conversion of organic matter into biogas.

The quality of the feedstock directly affects the biogas yield, which necessitates preliminary waste preparation, such as shredding, moistening, or adding catalysts (Golub *et al*., 2018).

The effectiveness of anaerobic digestion for various types of organic waste depends largely on its chemical composition, specifically the content of carbohydrates, proteins, and lipids. Waste with an elevated content of carbohydrates and lipids provides a greater biogas yield compared to materials that contain a considerable amount of cellulose or lignin.

Cogeneration plants, gas turbines, and internal combustion engines are used to convert biogas into electricity. Cogeneration plants are the most widespread due to their superior efficiency, which can reach 80%–90% when electricity and heat are produced simultaneously. Gas turbines are mainly used for large industrial facilities and have an efficiency of 30-40% when generating electricity only. Internal combustion engines are effective for small biogas plants with efficiencies of 25% to 45%, depending on the type and operating conditions. Table 1 summarises the key parameters of these technologies and their efficiencies.

Table 1. Key parameters of biogas production technologies and their efficiency

Technology	Temperature conditions (°C)	Efficiency (%)	Key advantages	Key disadvantages
Cogeneration plants	30-40 (mesophilic), 50-60 (thermophilic)	80-90	High efficiency, simultaneous generation of heat and electricity	Extensive capital expenditure
Gas turbines	50-60 (thermophilic)	30-40	High power, high reliability	Low efficiency without heat generation
Internal combustion engines	30-40 (mesophilic)	25-45	Effective for small plants	Emissions of harmful substances

Source: compiled by the authors based on J. Wang *et al.* (2023)

As can Table 1 demonstrates, the highest efficiency is achieved with cogeneration plants (80-90%) that combine heat and electricity generation. Gas turbines are highly efficient and reliable, but their efficiency is much lower (30-40%) when heat is not used. Internal combustion engines are characterised by relatively low efficiency (25-45%) and are only suitable for small installations.

Analysis of process parameters, such as temperature and biogas treatment methods, can determine the optimum conditions for increasing the efficiency of electricity generation. Furthermore, an essential aspect is the possibility of improving existing technologies through the introduction of new purification systems, the use of biomethane, and its integration into the overall energy system of Ukraine. The analysis of technological parameters shows that an increase in the efficiency of electricity generation is possible through optimisation of the anaerobic digestion process, use of high-quality raw materials, and improvement of biogas purification technologies. A prominent aspect is to ensure the stability of the process by maintaining the optimum temperature and controlling the pH level. In industrial environments, biogas plants provide stable electricity and heat production, but their efficiency can be increased by modernising gas purification technologies, improving the fermentation process and using hybrid plants that combine several energy sources. Figure 1 presents a schematic of the anaerobic digestion process, highlighting the key steps.

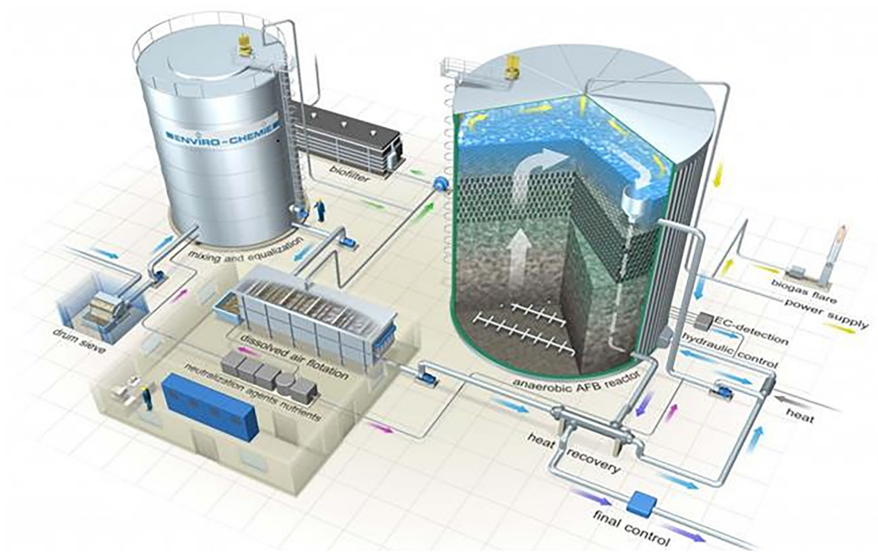

Figure 1. Schematic of the anaerobic digestion process
Source: compiled by the authors based on K.O. Samoychuk *et al.* (2020)

As shown in Figure 1, the biogas production process involves several key steps to ensure efficient generation and optimum use of the energy produced. First, the feedstock is pre-treated, which includes shredding, mixing, and emulsification to achieve a homogeneous consistency. The prepared feedstock is then fed to the Anaerobic AFB Reactor, where the fermentation process takes place in the absence of oxygen. Essential parameters controlled at this stage include temperature, humidity, pH, and microflora composition, which affect the efficiency of organic matter decomposition and methane production. After the fermentation process is complete, the biogas produced is purified from unwanted impurities such as hydrogen sulphide, ammonia, and carbon dioxide to produce high-purity biomethane. The process waste that is left after biogas separation is converted into recyclable materials that can be used in agriculture as fertilisers. Furthermore, the system includes temperature and energy control mechanisms that ensure optimum conditions for fermentation and increase the productivity of the biogas generator. This multi-level control system ensures stable biogas production and high efficiency of the production process.

Biogas purification and biomethane production

Biogas purification is a crucial step in the production process, as raw biogas contains impurities that can greatly reduce its energy value and cause technical problems during use. The key undesirable impurities are hydrogen sulphide (H_2S), ammonia (NH_3), CO_2, water vapour, and other volatile compounds. To produce high-quality biomethane that can be used for power generation or transported through gas pipelines, biogas must be thoroughly purified. Biogas treatment methods are divided into chemical, physical, and biological. Chemical methods involve the use of chemical absorbents such as sodium or calcium hydroxide, which effectively remove hydrogen sulphide and ammonia. Physical methods involve the use of technologies such as membrane separation, absorption, cryogenic separation, and adsorption. Membrane technologies provide a strong level of purification by separating methane from carbon dioxide using semi-permeable membranes.

Cryogenic separation is used to liquefy and further separate the gas mixture into its constituent components, which ensures biomethane purity of up to 98%. Adsorption methods involve the use of activated carbon or zeolites to remove impurities through a physical adsorption process. Biological purification methods involve the use of biofilters or bioreactors that remove hydrogen sulphide by oxidising it to elemental sulphur. A comparative analysis of biogas purification methods is presented in Table 2.

Table 2. Comparative analysis of biogas treatment methods by efficiency and economic feasibility

Purification method	H_2S removal efficiency (%)	CO_2 removal efficiency (%)	Economic feasibility	Key disadvantages
Membrane	95-98	85-95	High	High costs for membranes
Absorption	90-95	80-90	Medium	Requires chemical solvents
Cryogenic	98-99	98-99	Low	High energy costs
Adsorption	80-90	70-80	High	Low efficiency for high volumes
Biological	70-85	None	Medium	Process duration

Source: compiled by the authors based on AC Group (n.d.), V. Pérez *et al.* (2021)

As presented in Table 2, the cryogenic method provides the greatest treatment efficiency, but is also characterised by extensive energy costs, which makes it economically unfeasible for industrial use. Membrane and adsorption methods are the most promising due to their high treatment efficiency and relatively low implementation costs. Biological methods demonstrate average efficiency but have notable potential for improvement through improved designs of biofilters and bioreactors.

Purified biomethane can be used to generate electricity using cogeneration plants, gas turbines, and internal combustion engines. It can also be transported through gas transmission systems, ensuring the stability of energy networks. The stability of biomethane supply can be increased by storing it in backup storage facilities or integrating it with other renewable energy sources (Shram & Kachan, 2023).

The level of biogas purification from impurities determines the areas of its use. This can include biogas combustion for electricity production (generation and cogeneration – simultaneous production of electricity and heat), heat production (in boilers with corresponding burners), purification to biomethane and subsequent injection into the gas network, and biofuel production (bioLNG). Figure 2 presents the process of cooling and purification of biogas to biomethane, including the principal stages of removing unwanted impurities and improving gas quality.

The process consists of two principal stages: cooling and purification of biogas, and biogas upgrading to biomethane. The first stage involves gas dehydration, primary desulphurisation, H_2S separation, and filtration. The second stage involves the removal of other impurities, separation of CO_2, and gas dehydration to produce high-quality biomethane.

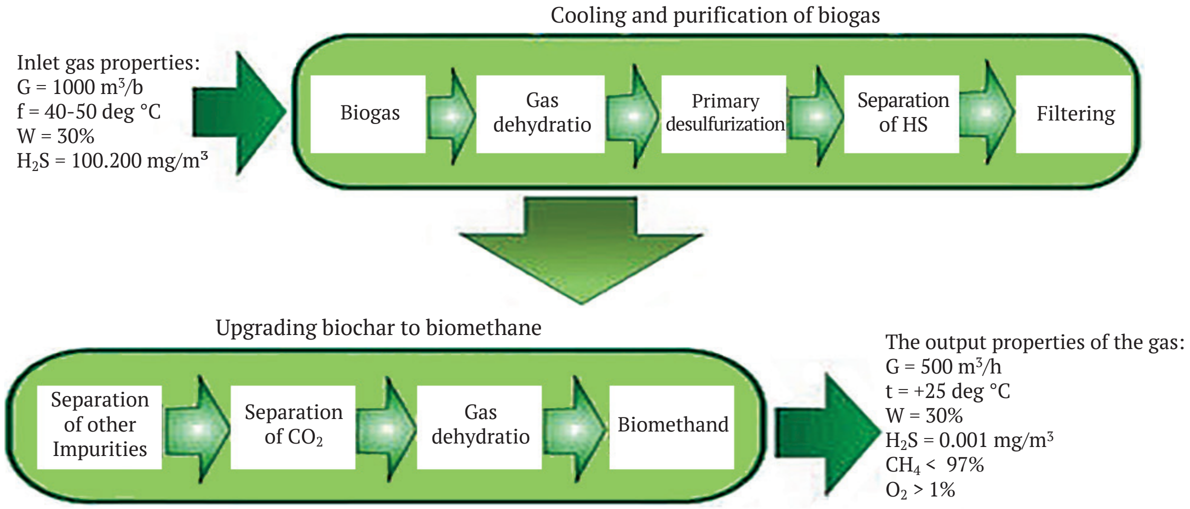

Figure 2. Schematic of the biogas cooling and purification process
Source: compiled by the authors based on AC Group (n.d.)

As Figure 2 demonstrates, the output is high-quality biomethane with a CH_4 content of over 97% and minimal impurities, making it suitable for electricity generation or transportation through gas pipelines. The use of such technologies helps to ensure the stability of energy grids and use biomethane as an alternative fuel, which helps to reduce greenhouse gas emissions and improve energy security.

Comparative analysis of electricity generation technologies

Electricity is produced from biogas and biomethane using a variety of technologies, including cogeneration plants, gas turbines, and internal combustion engines. The choice of a particular technology depends on a series of factors, including technical characteristics, environmental performance, economic feasibility, and integration into the overall energy system. Cogeneration plants are used to produce electricity and heat simultaneously. They demonstrate prominent efficiency, which varies between 80-90% due to the utilisation of heat released during the generation process. The principal advantages of cogeneration plants include high efficiency, economic feasibility for small and medium-sized plants, and the ability to provide continuous power generation. The disadvantages are extensive capital costs for the construction and operation of plants, as well as dependence on a stable supply of biogas. Gas turbines are an efficient way to generate electricity from biogas on an industrial scale. They provide high power and reliability, but their efficiency is still lower than that of cogeneration plants, typically by 30-40%. The principal advantage is the ability to operate at hot temperatures, which yields more energy per unit of fuel. At the same time, gas turbines are economically viable only for large-scale plants operating with pure biomethane. Internal combustion engines are efficient for small and medium-sized plants, providing an efficiency of 25-45%. These plants are well-suited for local power systems where electricity generation from biogas can be carried out autonomously. The key disadvantages of internal combustion engines include emissions and relatively low efficiency compared to other technologies (Gutarevych *et al.*, 2020). Table 3 compares the key technologies for generating electricity from biogas and biomethane in terms of technical characteristics, economic feasibility, and environmental performance.

Table 3. Comparative analysis of electricity generation technologies from biogas and biomethane

Technology	Efficiency (%)	Key advantages	Key disadvantages	Application area
Cogeneration plants	80-90	High efficiency, simultaneous heat and power generation	Extensive capital expenditure	Small and medium-sized plants
Gas turbines	30-40	High power, high reliability	Low efficiency without heat generation	Large industrial plants
Internal combustion engines	25-45	Effective for small plants	Emissions of harmful substances	Local power systems

Source: compiled by the authors based on V. Pérez *et al.* (2021), M.J.B. Kabeyi & O.A. Olanrewaju (2022a)

As Table 3 shows, cogeneration plants demonstrate the greatest efficiency (80-90%) due to the possibility of simultaneous production of heat and electricity. They are most suitable for small and medium-sized installations, although extensive capital costs are a major disadvantage. Gas turbines provide high power and reliability, but their efficiency without heat production stays relatively low (30-40%). Although internal combustion engines have a lower efficiency (25-45%), they are well-suited for local power systems, but the problem of harmful emissions continues to be relevant.

Apart from technical indicators, a valuable part of the analysis was the cost-effectiveness of different technologies. Research suggests that cogeneration units are the best option for integration into industrial and municipal systems where a constant supply of heat and electricity is required. Gas turbines and internal combustion engines are more suitable for large industrial plants or local power systems with limited access to centralised energy sources. The investigation of the prospects for integrating biogas plants into the overall energy system of Ukraine shows the possibility of efficient use of biomethane both for electricity generation and for its transportation through gas pipelines. Purified biomethane can be used as a backup energy source to ensure the stability of power grids in conditions of uneven load or peak consumption periods.

Figure 3 presents the scheme of integration of biogas plants into the overall energy system of Ukraine, including the possibility of using biomethane to stabilise the grid and provide backup power supply.

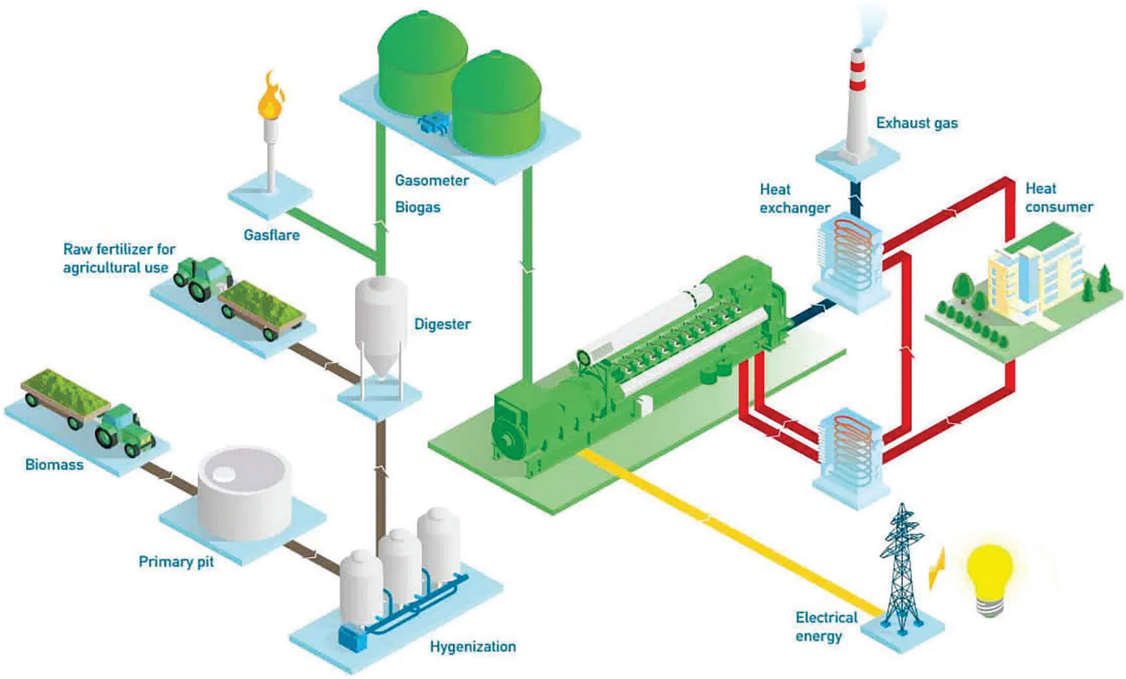

Figure 3. Scheme of integration of biogas plants into the general energy system of Ukraine
Source: compiled by the authors based on KTS Engineering (n.d.)

As Figure 3 shows, the key steps in the integration of biogas plants into the overall energy system of Ukraine include several key processes. First, the organic material is collected in a special pit where it is sterilised to remove harmful microbes. The processed material is then transferred to a bioreactor where it undergoes an anaerobic digestion process, resulting in the production of biogas. The generated biogas is stored in a storage tank to ensure a continuous supply of gas regardless of changes in production processes. Then, the biogas is treated to remove impurities and improve its quality to the level of biomethane. Finally, the purified biomethane is fed to a gas turbine plant that generates electricity and heat. Furthermore, biomethane can be transported through gas pipelines to stabilise the grid and provide backup power supply.

Development of recommendations for the integration of bioenergy technologies

Development of recommendations for the integration of bioenergy technologies into the energy system of Ukraine requires a detailed analysis of existing technological processes and development of effective approaches to their optimisation. The primary areas of improvement include increasing the efficiency of biogas purification processes, developing technical and organisational solutions to ensure the stability of energy supply and creating favourable conditions for the development of bioenergy industry at the state level.

Improvement of the efficiency of electricity generation technologies largely depends on the quality of biogas purification (Danylyshyn & Koval, 2023). According to the results of the comparative analysis, membrane technologies and cryogenic methods provide the greatest level of biogas purification, but they require extensive capital expenditures. Absorption and adsorption methods are more affordable, but less effective in removing carbon dioxide and other undesirable impurities. Optimisation of the biogas treatment process may involve combining multiple methods to achieve maximum efficiency at minimum cost. Particular attention is paid to improving pre-filtration systems and reducing the hydrogen sulphide content before feeding to the major treatment systems. To improve the efficiency of bioenergy plants, it is proposed to develop standardised technological processes that factor in the characteristics of distinct types of feedstock and industrial conditions. Specifically, it is vital to improve cogeneration units that simultaneously produce heat and electricity, which enables the most efficient use of biogas energy potential. Furthermore, it is necessary to develop methods for adapting gas turbines and internal combustion engines to work with purified biomethane, which will reduce emissions of harmful substances and increase the efficiency of energy conversion.

Ukraine's current energy infrastructure must be modernised to ensure the integration of biogas plants into the overall energy system. This includes the creation of new connections to gas transmission systems and the modernisation of existing networks for biomethane transportation. Proposed measures include the construction of special gas pipelines for transporting purified biomethane and the creation of backup energy storage systems to ensure the stability of energy supply. It is also essential to create a centralised system for monitoring and controlling biogas plants, which will allow for real-time monitoring of their performance (Atamanyuk *et al.,* 2015).

To accelerate the development of bioenergy in Ukraine, it is necessary to develop state support programmes, including financial incentives, tax benefits, and simplified licensing procedures. It is proposed to create a system of "green" tariffs for electricity generation from biomethane, as well as to establish preferential conditions for enterprises that purify biogas to the level of biomethane. Particular attention should be paid to the development of legislation regulating the use of biomethane in gas transmission systems and energy networks. Legislative initiatives adopted in Ukraine are directly aimed at integrating bioenergy technologies into the country's overall energy system, specifically for the production of electricity from biogas and biomethane. The adoption of the Law of Ukraine No. 1820-IX "On Amendments to Certain Laws of Ukraine Regarding the Development of Biomethane Production" (2021) creates a legal framework for the functioning of the biomethane market, particularly through the introduction of an electronic register of guarantees of origin of biomethane. This mechanism not only facilitates the export of biogas and biomethane to EU countries but also ensures that it can be used within Ukraine to generate electricity and stabilise energy networks. Thanks to the certification of biomethane and its compliance with environmental standards, Ukrainian energy companies will be able to use it as an alternative fuel, which helps to reduce dependence on traditional fossil energy sources (Kalinichenko *et al.,* 2019).

Furthermore, the adoption of the Law of Ukraine No. 2320-IX "On Waste Management" (2024) stimulates the use of organic waste for biomethane production, which is a crucial step towards expanding the resource base of renewable energy. This approach is in line with the European principles of the circular economy and creates conditions for improving the energy efficiency of industrial and utility companies through biogas plants. This is crucial for Ukraine, which is striving to achieve energy independence and stability of its energy system. The adoption of DSTU EN 16723-1:2023 (2023), which regulates the technical requirements for biomethane for injection into gas transmission networks, also considerably influences the integration of biogas plants into the Ukrainian energy system. The compliance of Ukrainian technologies with European standards will not only facilitate the export of biomethane but also increase the efficiency of its domestic use in the country's energy system. This includes the possibility of using purified biomethane both to generate electricity and to provide backup capacity at critical times. Thus, the adopted laws and standards create conditions for the effective integration of biogas plants into the overall energy system of Ukraine, which will not only increase the stability of electricity supply but also reduce dependence on fossil fuels, ensuring the country's environmental and energy security.

Integration of biogas into Ukraine's energy system is a major step towards improving energy efficiency and ensuring stable energy supply. The use of biogas in industrial and municipal facilities requires the improvement of biogas treatment, generation, and storage technologies. This involves the creation of special infrastructure facilities, including biogas plants and storage systems, which will help stabilise the power grid during peak loads or crisis situations. Furthermore, it is vital to ensure the integration of biogas technologies into the overall energy system by developing technical standards that regulate the quality of biogas for use in electricity and heat generation. The compatibility of biogas plants with existing energy networks is a critical aspect that requires the development of methods for power balancing and adaptation of equipment to the conditions of centralised energy supply (Sirko *et al*., 2023). Table 4 presents the key recommendations for optimising technological processes to integrate bioenergy plants into the Ukrainian energy system.

Table 4. Recommendations on optimisation of technological processes to integrate bioenergy plants into the energy system of Ukraine

Optimisation area	Proposed measures	Expected outcomes
Biogas treatment	Combination of purification methods to maximise efficiency	Reduced impurities, improved biogas quality
Improvement of technological processes	Modernisation of cogeneration units, adaptation of gas turbines and internal combustion engines	Improved energy efficiency and environmental friendliness
Infrastructure solutions	Construction of gas pipelines, creation of backup energy storage systems	Stability of supply and flexibility of energy networks
Government support	Financial incentives, tax breaks, "green" tariffs	Increased investment in bioenergy

Source: compiled by the authors

As Table 4 shows, the principal recommendations for optimising technological processes include improving biogas purification methods, creating special systems for biogas transportation, and designing a legislative framework to stimulate bioenergy development. Thus, the integration of biogas into Ukraine's energy systems will help reduce dependence on fossil fuels, increase energy security, and create conditions for sustainable development of renewable energy.

The study of the possibilities of using purified biogas to stabilise energy networks confirmed its potential as a reliable backup energy resource capable of ensuring uninterrupted power supply during peak loads or crisis situations. The integration of biogas plants into the overall energy system of Ukraine involves the introduction of government incentive mechanisms, the creation of specialised infrastructures for the transportation and storage of biomethane, and the optimisation of technological processes for electricity generation (Kucher *et al*., 2022). The recommendations include improving biogas purification methods, modernising power generation facilities, integrating biogas plants into gas transmission systems, and creating state programmes to support bioenergy development. The proposed measures can greatly improve the energy efficiency of biogas and biomethane use in Ukraine, ensure reliable electricity supply, and contribute to reducing dependence on fossil fuels and improving the environmental situation in the country.

The findings of the present study proved the prospects of integrating biogas technologies into Ukraine's energy system as one of the key areas of renewable energy development. The research suggests that the use of biogas and biomethane for electricity generation is technically efficient and can help reduce dependence on fossil fuels and improve the environmental situation. A comparison with current international research revealed that the findings of the present study correlated with global trends in bioenergy. A. Ilari *et al.* (2022) confirmed that the use of agricultural and forest residues in bioenergy can greatly reduce the carbon footprint of power plants, but the efficiency of such plants is highly dependent on the quality of raw materials and the stability of supply. This is in line with the conclusions of the present study on the need for preliminary preparation of feedstock and control of technological parameters of anaerobic digestion.

O. Awogbemi *et al.* (2024) focused on the transformation of agricultural waste into highly efficient biofuels using combined pretreatment methods, which fully coincided with the conclusions of the present study on the feasibility of thermochemical and enzymatic treatment to increase biogas yields. Z. Xie *et al.* (2025) proposed an innovative approach to biogas utilisation by converting it into carbon nanomaterials. Although this technology is not yet widely used in industry, it demonstrates the potential for multifunctional use of biogas and emphasises the significance of its high-quality treatment, which was also confirmed in the present study. R. Stavinskiy *et al.* (2021) investigated the issue of improving energy efficiency through the improvement of transformer systems, but their study was indirectly related to the subject under study, as it concerned the technical improvement of power plants. M.U.B. Khawer *et al.* (2022) focused on the production of biogas and biohydrogen through anaerobic digestion of wastewater. Their findings confirmed that the use of food waste and domestic wastewater can be an effective source for biogas production. The data are consistent with the findings of the present study regarding the possibility of using various types of organic materials for biogas generation. S. Abanades *et al.* (2022b) provided a conceptual overview of sustainable electricity production from biogas. Their study confirmed that current technologies for biogas purification to biomethane are effective in ensuring its suitability for transportation through gas networks, which correlated with the findings obtained for membrane and adsorption purification methods. A.M. Shinde *et al.* (2021) assessed the life cycle of biogas and biomethane production for electricity generation. The researchers addressed the economic feasibility of electricity production from biogas on an industrial scale, which coincided with the conclusions about the prospects for the use of cogeneration plants and internal combustion engines.

U. Brémond *et al.* (2021) analysed the prospects for the development of the European biogas market until 2030, pointing out the need to improve biogas treatment and storage technologies to ensure a stable energy supply. Their conclusions were consistent with the present study's recommendations for improving biogas treatment processes. M.J.B. Kabeyi & O.A. Olanrewaju (2022b) detailed the technologies for converting biogas to electricity, emphasising the role of cogeneration systems as the most efficient solution for generating electricity from biogas. Their study confirmed the present findings obtained on the high efficiency of cogeneration plants and the prospects for their integration into the Ukrainian energy system. A. Admasu *et al.* (2022) described experimental and simulation studies of biogas production from industrial wastewater. Their findings demonstrate the effectiveness of using waste of various origins for biogas production, which was consistent with studies on the possibility of increasing the efficiency of anaerobic digestion through the improvement of technological processes.

M.P.C. Volpi *et al.* (2023) analysed the economic aspects of biogas production from waste using co-digestion technology in bioenergy sugar biorefineries. This study confirmed that biomethane production is more cost-effective than electricity production, considering the possibility of transporting it through existing gas networks. This conclusion coincided with the presented recommendations for the integration of biomethane into Ukraine's gas transmission systems to ensure energy security. R. Bedoić *et al.* (2021) examined the synergies between feedstock fees and Power-to-Gas technology, which can increase the economic viability of biomethane production. The researchers highlighted that the use of energy storage technologies and hybrid systems can markedly improve the efficiency of electricity generation from biogas. This is in line with the findings of the current study regarding the need to introduce energy storage systems and modernise existing biogas plants to optimise the use of the energy produced. B. Stürmer *et al.* (2021) conducted a regional comparative analysis of agricultural biogas production, emphasising that the efficiency of technologies depends heavily on the type of feedstock and regional conditions. The researchers confirmed the significance of developing specialised approaches to biogas production in Ukraine, considering local specifics. These data are consistent with the findings of the present study, which indicated the need to adapt anaerobic digestion technologies to the specifics of Ukrainian regions.

G. Geletukha *et al.* (2022) investigated ways to replace Russian natural gas through biogas and biomethane production in Ukraine. Their conclusions emphasised the role of developing a regulatory framework and creating infrastructure for transporting biomethane through existing gas networks, which was fully consistent with the presented recommendations to integrate biogas plants into the overall energy system of Ukraine to ensure energy independence. K. Redko *et al.* (2022) analysed the development of green energy as a way to ensure Ukraine's energy independence. The researchers emphasised the significance of state support and promotion of renewable energy sources, including biogas technologies. These conclusions fully coincided with the study's recommendations to develop mechanisms to stimulate the development of bioenergy at the state level. D. Thiruselvi *et al.* (2021) and A. Veeramuthu *et al.* (2025) provided a critical overview of global trends in biogas technologies, including methods for improving them for use in fuel cells and energy networks. Their study focused on the need to improve biogas purification technologies, which is consistent with the findings on the significance of optimising biogas purification processes to increase the efficiency of electricity generation and biomethane use in industrial settings.

Thus, the analysis of sources confirmed that the development of biogas technologies in Ukraine requires a comprehensive approach, including the improvement of biogas purification methods, creation of infrastructure for its transportation and storage, as well as the introduction of mechanisms for government incentives for bioenergy development. The integration of biomethane into Ukraine's gas transmission systems can substantially increase the efficiency of renewable energy sources and ensure the country's energy security.

CONCLUSIONS

The study confirmed that electricity production from biogas and biomethane is a promising area for ensuring Ukraine's energy independence. The analysis of modern biogas production technologies revealed the significance of optimising anaerobic digestion processes, improving biogas purification methods and integrating biomethane plants into the overall energy system. The findings showed that cogeneration technologies provide the greatest efficiency of 80-90% due to the possibility of simultaneous production of heat and electricity. Gas turbines, which provide power and reliability, have an efficiency of 30-40%. Internal combustion engines are characterised by relatively low efficiency (25-45%) but are well suited for local systems with limited access to centralised energy sources. At the same time, emissions of harmful substances are still a major disadvantage of these plants.

Purification of biogas to the level of biomethane is a critical step for its further use in energy systems. Membrane technologies provide a purification efficiency of up to 95-98%, which makes them the most promising due to their high economic feasibility. Cryogenic separation demonstrates the highest purification efficiency (98-99%) but requires extensive energy costs. Absorption and adsorption methods are more affordable but less efficient for large volumes of biogas. Biological methods, specifically biofilters, have the potential for further improvement.

The findings also confirmed the significance of creating an efficient infrastructure for transporting and storing biomethane, as well as developing technical standards to regulate its quality. A prominent aspect is to ensure the compatibility of biomethane technologies with existing gas networks and the introduction of government support programmes, including tax benefits and "green" tariffs. The proposed measures will contribute to the development of the national energy system, increase its sustainability and environmental safety. The use of purified biomethane can substantially improve the efficiency of energy networks and reduce dependence on fossil energy sources. Specifically, the use of cogeneration units, gas turbines, and internal combustion engines can ensure the stability of energy supply even in crises or under conditions of uneven load.

Thus, the findings of the present study confirmed that electricity production from biogas and biomethane is a promising area for ensuring Ukraine's energy independence. Further research should be aimed at improving biogas purification methods, creating efficient technologies for its use, and expanding the infrastructure for biomethane transportation, which will ensure the stability of energy supply and improve the country's energy security.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Abanades, S., *et al.* (2022a). A critical review of biogas production and usage with legislations framework across the globe. *International Journal of Environmental Science and Technology*, 19, 3377-3400. doi: 10.1007/s13762-021-03301-6.

[2] Abanades, S., *et al.* (2022b). A conceptual review of sustainable electrical power generation from biogas. *Energy Science & Engineering*, 10(2), 630-655. doi: 10.1002/ese3.1030.

[3] AC Group. (n.d.). *Biogas purification*. Retrieved from https://ac-group.in.ua/blog/biogas_purification/.

[4] Admasu, A., Bogale, W., & Mekonnen, Y.S. (2022). Experimental and simulation analysis of biogas production from beverage wastewater sludge for electricity generation. *Scientific Reports*, 12, article number 9107. doi: 10.1038/s41598-022-12811-3.

[5] Amhamed, A.I., Al Assaf, A.H., Le Page, L.M., & Alrebei, O.F. (2024). Alternative sustainable aviation fuel and energy (SAFE) – a review with selected simulation cases of study. *Energy Reports*, 11, 3317-3344. doi: 10.1016/j.egyr.2024.03.002.

[6] Atamanyuk, I., Kondratenko, Y., Shebanin, V., & Mirgorod, V. (2015). Method of polynomial predictive control of fail-safe operation of technical systems. In *The experience of designing and application of CAD systems in microelectronics* (pp. 248-251). Lviv: Lviv Polytechnic Publishing House. doi: 10.1109/CADSM.2015.7230848.

[7] Awogbemi, O., von Kallon, D.V., & Ray, R.C. (2024). Conversion of agriculture residues for bioenergy production. In J. Arora, A. Joshi & R.C. Ray (Eds.), *Transforming agriculture residues for sustainable development: From waste to wealth* (pp. 273-294). Cham: Springer. doi: 10.1007/978-3-031-61133-9_12.

[8] Bedoić, R., Dorotić, H., Schneider, D.R., Čuček, L., Ćosić, B., Pukšec, T., & Duić, N. (2021). Synergy between feedstock gate fee and power-to-gas: An energy and economic analysis of renewable methane production in a biogas plant. *Renewable Energy*, 173, 12-23. doi: 10.1016/j.renene.2021.03.124.

[9] Brémond, U., Bertrandias, A., Steyer, J.P., Bernet, N., & Carrere, H. (2021). A vision of European biogas sector development towards 2030: Trends and challenges. *Journal of Cleaner Production*, 287, article number 125065. doi: 10.1016/j.jclepro.2020.125065.

[10] Danylyshyn, V., & Koval, M. (2023). Analysis of biogas production and prospects for the development of biogas technologies in Ukraine. *Ukrainian Black Sea Region Agrarian Science*, 27(3), 90-102. doi: 10.56407/bs.agrarian/3.2023.90.

[11] Das, J., Ravishankar, H., & Lens, P.N.L. (2022). Biological biogas purification: Recent developments, challenges and future prospects. *Journal of Environmental Management*, 304, article number 114198. doi: 10.1016/j.jenvman.2021.114198.

[12] DSTU EN 16723-1:2023. (2023). *Natural gas and biomethane for use in transport and biomethane for injection into the natural gas network. Part 1. Technical characteristics of biomethane for injection into the natural gas network*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=102506.

[13] Gadirli, G., Pilarska, A.A., Dach, J., Pilarski, K., Kolasa-Więcek, A., & Borowiak, K. (2024). Fundamentals, operation and global prospects for the development of biogas plants – a review. *Energies*, 17(3), article number 568. doi: 10.3390/en17030568.

[14] Geletukha, G., Zheliezna, T., Drahniev, S., & Haidai, O. (2022). Analysis of actions for Ukraine to replace Russian natural gas. *Ecological Engineering & Environmental Technology*, 23(4), 1-9. doi: 10.12912/27197050/149458.

[15] Golub, G., Kukharets, S., Tsyvenkova, N., Yarosh, Y., & Chuba, V. (2018). Experimental study into the influence of straw content in fuel on parameters of generator gas. *Eastern-European Journal of Enterprise Technologies*, 5(8-95), 76-86. doi: 10.15587/1729-4061.2018.142159.

[16] Gutarevych, Y., Mateichyk, V., Matijošius, J., Rimkus, A., Gritsuk, I., Syrota, O., & Shuba, Y. (2020). Improving fuel economy of spark ignition engines applying the combined method of power regulation. *Energies*, 13(5), article number 1076. doi: 10.3390/en13051076.

[17] Ilari, A., Duca, D., Boakye-Yiadom, K.A., Gasperini, T., & Toscano, G. (2022). Carbon footprint and feedstock quality of a real biomass power plant fed with forestry and agricultural residues. *Resources*, 11(2), article number 7. doi: 10.3390/resources11020007.

[18] Kabeyi, M.J.B., & Olanrewaju, O.A. (2022a). Biogas production and applications in the sustainable energy transition. *Journal of Energy*, 2022(1), article number 8750221. doi: 10.1155/2022/8750221.

[19] Kabeyi, M.J.B., & Olanrewaju, O.A. (2022b). Technologies for biogas to electricity conversion. *Energy Reports*, 8(16), 774-786. doi: 10.1016/j.egyr.2022.11.007.

[20] Kalinichenko, A., Havrysh, V., & Atamanyuk, I. (2019). The acceptable alternative vehicle fuel price. *Energies*, 12(20), article number 3889. doi: 10.3390/en12203889.

[21] Khawer, M.U.B., Naqvi, S.R., Ali, I., Arshad, M., Juchelková, D., Anjum, M.W., & Naqvi, M. (2022). Anaerobic digestion of sewage sludge for biogas & biohydrogen production: State-of-the-art trends and prospects. *Fuel*, 329, article number 125416. doi: 10.1016/j.fuel.2022.125416.

[22] Kolbasenko, O., Kundenko, M., Sadovoy, O., Rudenko, A., & Mardziavko, V. (2023). Research of the vibration mode of combustion of Water-Fuel emulsion for improving the efficiency indicators of the power plant. In *2023 IEEE 5th international conference on modern electrical and energy system* (pp. 1-7). Kremenchuk: Institute of Electrical and Electronics Engineers. doi: 10.1109/MEES61502.2023.10402443.

[23] KTS Engineering. (n.d.). *Biogas*. Retrieved from https://www.kts-eng.com/solutions/biogaz/.

[24] Kucher, O., Hutsol, T., Glowacki, S., Andreitseva, I., Dibrova, A., Muzychenko, A., Szeląg-Sikora, A., Szparaga, A., & Kocira, S. (2022). Energy potential of biogas production in Ukraine. *Energies*, 15(5), article number 1710. doi: 10.3390/en15051710.

[25] Law of Ukraine No. 1820-IX "On Amendments to Certain Laws of Ukraine Regarding the Development of Biomethane Production". (2021, October). Retrieved from https://zakon.rada.gov.ua/laws/show/1820-IX.

[26] Law of Ukraine No. 2320-IX "On Waste Management". (2024, November). Retrieved from https://zakon.rada.gov.ua/laws/show/2320-20/ed20241115#Text.

[27] Madondo, N.I., Tetteh, E.K., Rathilal, S., & Bakare, B.F. (2022). Effect of an electromagnetic field on anaerobic digestion: Comparing an electromagnetic system (ES), a microbial electrolysis system (MEC), and a control with No external force. *Molecules*, 27(11), article number 3372. doi: 10.3390/molecules27113372.

[28] Mamica, Ł., Mazur-Bubak, M., & Wróbel-Rotter, R. (2022). Can biogas plants become a significant part of the new Polish energy deal? Business opportunities for Poland's biogas industry. *Sustainability*, 14(3), article number 1614. doi: 10.3390/su14031614.

[29] Pérez, V., Moltó, J.L., Lebrero, R., & Muñoz, R. (2021). Ectoine production from biogas in waste treatment facilities: A techno-economic and sensitivity analysis. *ACS Sustainable Chemistry & Engineering,* 9(51), 17371-17380. doi: 10.1021/acssuschemeng.1c06772.

[30] Redko, K., Denyshchenko, L., Dobrovolska, O., Lukyanenko, N., & Kyryllova, Y. (2022). Development of green energy as a way to energy independence of the national economy: Literature review. *Futurity Economics & Law*, 2(4), 78-94. doi: 10.57125/FEL.2022.12.25.05.

[31] Rodrigues, B.C.G., de Mello, B.S., Grangeiro, L.C., Dussan, K.J., & Sarti, A. (2025). The most important technologies and highlights for biogas production worldwide. *Journal of the Air & Waste Management Association*, 75(2), 87-108. doi: 10.1080/10962247.2024.2393192.

[32] Samoychuk, K.O., Verkholantseva, V.O., & Livik, N.V. (2020). *Use of wind energy and biofuels in the machinery industry*. Melitopol: Tavria State Agrotechnological University.

[33] Shinde, A.M., Dikshit, A.K., Odlare, M., Thorin, E., & Schwede, S. (2021). Life cycle assessment of bio-methane and biogas-based electricity production from organic waste for utilization as a vehicle fuel. *Clean Technologies and Environmental Policy*, 23, 1715-1725. doi: 10.1007/s10098-021-02054-7.

[34] Shram, O., & Kachan, Yu. (2023). Determination of appropriate energy storage devices in the power grids of industrial enterprises. *Journal of Kryvyi Rih National University*, 21(2), 52-59. doi: 10.31721/2306-5451-2023-1-57-52-59.

[35] Sirko, Z., Okhrimenko, S., Tsapko, O., Torchilevsky, D., Starysh, E., & Gritsun, V. (2023). Ejection wind power plant. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 19(3), 1-10. doi: 10.31548/dopovidi3(103).2023.015.

[36] Stavinskiy, R., Vakhonina, L., Avdieieva, E., & Sadovoy, O. (2021). Calculation of losses in steel and improvement of a three-phase transformer with a twisted spatial magnetic circuit. In *2021 IEEE international conference on modern electrical and energy systems* (pp. 1-4). Kremenchuk: Institute of Electrical and Electronics Engineers. doi: 10.1109/MEES52427.2021.9598690.

[37] Stürmer, B., Leiers, D., Anspach, V., Brügging, E., Scharfy, D., & Wissel, T. (2021). Agricultural biogas production: A regional comparison of technical parameters. *Renewable Energy*, 164, 171-182. doi: 10.1016/j.renene.2020.09.074.

[38] Syahri, S.N.K., Hasan, H.A., Abdullah, S.R.S., Othman, A.R., Abdul, P.M., Azmy, R.F.H.R., & Muhamad, M.H. (2022). Recent challenges of biogas production and its conversion to electrical energy. *Journal of Ecological Engineering*, 23(3), 251-269. doi: 10.12911/22998993/146132.

[39] Thiruselvi, D., Kumar, P.S., Kumar, M.A., Lay, C., Aathika, S., Mani, Y., Jagadiswary, D., Dhanasekaran, A., Shanmugam, P., Sivanesan, S., & Show, P. (2021). A critical review on global trends in biogas scenario with its up-gradation techniques for fuel cell and future perspectives. *International Journal of Hydrogen Energy*, 46(31), 16734-16750. doi: 10.1016/j.ijhydene.2020.10.023.

[40] Veeramuthu, A., Kumar, G., Lakshmanan, H., Chandramughi, V.P., Flora, G., Kothari, R., & Piechota, G. (2025). A critical review of biogas production and upgrading from organic wastes: Recent advances, challenges and opportunities. *Biomass and Bioenergy,* 194, article number 107566. doi: 10.1016/j.biombioe.2024.107566.

[41] Volpi, M.P.C., Fuess, L.T., & Moraes, B.S. (2023). Economic performance of biogas production and use from residues co-digestion in integrated 1G2G sugarcane biorefineries: Better electricity or biomethane?. *Energy Conversion and Management*, 277, article number 116673. doi: 10.1016/j.enconman.2023.116673.

[42] Wang, J., Ma, D., Lou, Y., Ma, J., & Xing, D. (2023). Optimization of biogas production from straw wastes by different pretreatments: Progress, challenges, and prospects. *Science of the Total Environment*, 905, article number 166992. doi: 10.1016/j.scitotenv.2023.166992.

[43] Xie, Z., Huang, E., Turaczy, K.K., Garg, S., Hwang, S., Kasala, P.R., Liu, P., & Chen, J.G. (2025). Biogas sequestration to carbon nanofibers via tandem catalytic strategies. *Nature Chemical Engineering*, 2, 118-129. doi: 10.1038/s44286-025-00182-1.

Олексій Садовий
Кандидат технічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-7369-0714

Дмитро Кошкін
Кандидат технічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0002-6927-8487

Володимир Мартиненко
Кандидат технічних наук, доцент
Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна
https://orcid.org/0000-0003-4067-3640

Віталій Соколік
Магістр
Миколаївський національний аграрний університет
54008, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна
https://orcid.org/0009-0006-0264-6333

Виробництво електроенергії з біогазу: сучасні технології та перспективи для енергетичної незалежності України

Анотація. Виробництво електроенергії з біогазу та біометану є перспективним напрямом розвитку відновлюваної енергетики, який може суттєво зменшити залежність України від викопного палива, скоротити обсяги викидів парникових газів та підвищити рівень енергетичної безпеки. Метою дослідження був аналіз сучасних технологій виробництва електроенергії з біогазу та біометану, оцінка їхньої ефективності, технічних переваг, недоліків та можливостей інтеграції у загальну енергетичну систему України. Методологія дослідження включає порівняльний аналіз когенераційних установок, двигунів внутрішнього згоряння та газових турбін, які використовуються для генерації електроенергії з біогазу, а також методів очищення біогазу до рівня біометану. Аналіз проводився з урахуванням технічної ефективності, економічної доцільності та екологічної безпеки. Результати дослідження показали, що когенераційні установки демонструють найвищий коефіцієнт корисної дії, який коливається в межах 80-90 %, завдяки одночасному виробництву теплової та електричної енергії. Газові турбіни забезпечують коефіцієнт корисної дії на рівні 30-40 %, а двигуни внутрішнього згоряння – 25-45 %. Порівняльний аналіз методів очищення біогазу виявив, що мембранні технології є найбільш перспективними завдяки високій ефективності очищення (95-98 %) та економічній доцільності. Інші методи, такі як абсорбційні, кріогенні та адсорбційні, мають обмеження у застосуванні через високі енергетичні витрати або низьку ефективність очищення. Встановлено, що очищення біогазу до біометану дозволяє використовувати його для генерації електроенергії, транспортування газопроводами та забезпечення стабільності енергомереж, особливо у періоди пікового навантаження. Розроблені рекомендації включають вдосконалення технологій очищення біогазу, створення інфраструктури для його транспортування та зберігання, а також розробку механізмів державного стимулювання розвитку біоенергетики. Використання біоенергетичних технологій може забезпечити стабільність енергетичної системи України, підвищити її ефективність та знизити залежність від традиційних джерел енергії

Ключові слова: відновлювана енергетика; біометан; когенераційні установки; газові турбіни; двигуни внутрішнього згоряння; газотранспортні системи