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DIRECTIONS FOR USING THE BIOENERGY POTENTIAL OF AGRICULTURE FOR THE PRODUCTION OF BIOMETHANE AND DIGESTATE

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ABSTRACT

Biomethane production is in line with the idea of a circular economy, as it converts streams of agricultural by-products or industrial and domestic waste into energy, while ensuring the recycling of nutrients to agricultural land. The generally accepted opinion of experts is that «biomethane is the future of biogas». Biomethane can be produced both for domestic consumption (feeding into the gas network with subsequent use for the production of electricity and/or thermal energy, or as motor fuel for vehicles), and potentially for export to European countries.

It was determined that obtaining biogas from agricultural waste makes it possible to partially solve a number of problems facing the agricultural sector of the country: economic - increasing the competitiveness of agricultural products due to the reduction of energy costs during its production; energy - own production of fuel, ensuring the energy independence of agricultural enterprises; agrochemical - obtaining environmentally friendly fertilizers; ecological - disposal of organic waste that harms the environment; financial - reducing costs for the disposal of organic waste and the purchase of traditional energy carriers; social - creation of new jobs.

It was determined that agricultural waste and household waste have great energy potential. From the point of view of biofuel and energy production, waste from both the crop and livestock sectors is appropriate, while the potential of both agricultural enterprises and households should be developed, after which they can be used jointly in the implementation of bioenergy projects at the community level.

It was noted that the development of biomethane production in Ukraine allows: to reduce the volume of natural gas imports and partially realize surpluses on the energy market; postal development dates of high-tech production of equipment for biogas plants; create additional jobs at bioenergy enterprises; to provide agricultural producers with organic fertilizers (digestate); to worsen the cost of biomethane production in the case of using the developed scheme of operation of the production bioenergy cluster.

The paper calculates the available potential of the agro-industrial complex in agrobiomass and theoretical volumes of biofuel production from it to ensure energy

independence of the industry. It was determined that in the structure of the potential for biogas production, the main raw materials are post-harvest residues and corn silage, and the total potential for biogas production from waste amounts to more than 9.6 billion m^3. It was investigated that the following measures should be taken to increase the production and use of biomethane: reorient the existing biogas plants to the production of biomethane; establish cooperation with producers of agricultural products focused on the purchase of waste from this sector of the economy for biogas production; apply biomethane liquefaction technologies for use in transport; ensure the gradual accession of Ukraine to the European biomethane trading system.

The monograph was written within the framework of the state theme «Development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring energy independence of the agro-industrial complex». State registration number 0123U100311.

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1. Using the potential of biomethane and digestate production in Ukraine as a direction to ensure the country's energy security

The monographic study is devoted to the issue of biomethane production, which corresponds to the idea of a circular economy, since it transforms streams of agricultural by-products or industrial and household waste into energy, while ensuring the recirculation of nutrients to agricultural lands. Biomethane can be produced both for domestic consumption (feeding into the gas network with subsequent use for the production of electricity and/or thermal energy, or as motor fuel for vehicles), and potentially for export to European countries. The aim of the monographic study is to develop directions for the production and processing of products of the agro-industrial complex into biomethane with the aim of increasing Ukraine's energy independence and reducing the environmental impact on the external environment. The subject of research is processes bio-organic technologies of biomethane production. The scientific novelty of the obtained research results is that for the first time, the optimal mode of using agrobiomass for the production of biomethane was established experimentally. The research methodology is based on experimental studies of scientific topics on the topic: «Development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring the energy independence of the agricultural sector». In the preparation of this monograph, materials developed by the authors as part of applied research financed by the state budget of Ukraine were partially used.

Currently, in the conditions of the Russian invasion and refusal to import energy carriers from Belarus and the Russian Federation, the search for ways to provide the Ukrainian economy with alternative sources of energy resources is necessary in the short term. The fastest solution is to use the existing potential of the agro-industrial complex for the production of energy carriers from biomass and products of the processing industry. After all, the development of one's own production of natural resources is more expensive and requires relatively longer terms of implementation. The use of advanced technologies for growing and processing agrobiomass into alternative energy sources can be achieved in the short term and significantly increase the production of biogas and solid biofuel during 2022. At the same time, it will give an impetus to the creation of labor force in rural areas and save the foreign exchange reserves of the state, which will not need to be spent on the purchase of high-cost energy carriers. The development of an effective system of crop rotation and processing of agrobiomass into alternative energy sources is a necessary component of ensuring Ukraine's energy security. Without a threat to food security and the export potential of the state, about 10 million hectares of agricultural land can be used for growing energy crops with their subsequent processing into biofuels, in order to ensure the energy independence of the agro-industrial complex and Ukraine [1, 4, 14].

Biomethane, as a close analogue of natural gas, can be used for the production of thermal and electrical energy, as transport motor fuel, as well as in everyday life and as a raw material for the chemical industry. Biomethane production is in line with the idea of a circular economy, as it converts streams of agricultural by-products or industrial and domestic waste into energy, while ensuring the recycling of nutrients to agricultural land. The generally accepted opinion of experts is that «biomethane is the future of biogas». Biomethane can be produced both for domestic consumption (feeding into the gas network with subsequent use for the production of electricity and/or thermal energy, or as motor fuel for vehicles), and potentially for export to European countries. The EU countries have set a substitution of natural gas consumption by renewable gases (biomethane, green hydrogen) by 2050 as one of the goals of climate neutrality within the Green Deal framework. For this purpose, the legal framework is being created and significant investment projects are being prepared for implementation. Ukraine has all the potential to join this process.

Biogas production in Ukraine is stimulated by feed-in-tariff (green tariff) for electricity produced from biogas. Almost all Ukrainian biogas plants produce electricity with successive national power grid delivery. By now, there is no specific legislation to facilitate production and utilization of biomethane. The average annual growth of the biogas sector was 65% in 2017-2019. If at the end of 2017 the total installed capacity of biogas plants was 29 MWe, then at the end of 2019 it was already

76 MWe. During this time period electricity production increased from 93.5 to 247.4 GWh. About 40% of electricity produced from landfill gas (LFG) at municipal solid waste (MSW) landfills and waste dumps. The rest 60% of electricity produced by agricultural biogas plants. At least 26 agricultural biogas plants were under operation in Ukraine in 2019. The individual projects ranged from 125 kWe to 12 MWe installled capacity. Some of the small projects produce electricity without green tariff, two projects produce only heat for own industry needs. At the same time there were 22 LFG recovery systems, all of them with electricity production. Despite the limited number of implemented agricultural biogas plants, their technical scope covers a wide range of industries and different types of feedstock. Ukrainian biogas plants are erected at pig, cattle, chicken farms, at sugar plants, breweries, and food production enterprises, using a broad diversity of raw materials such as pig and cattle manure, chicken litter, maize and sugar sorghum silage, sugar beet pulp and molasses, food treatment waste and industry waste water.

According to the studies of Ukrainian Bioenergy Association (UABio), Ukrainian's biogas/biomethane production potential for digestion technology was estimated to be about 6.8 bcm of methane in 20182 . The potential includes biogas from agricultural waste and by-products (2.8 bcm), landfill gas and biogas obtained from industrial and municipal wastewater (1.0 bcm), and biogas from maize silage (3.0 bcm). Expert estimates show that the potential for biogas/biomethane production may increase up to 17 bcm in 2050. Such significant growth can occur due to increase of industrial production, growth of raw material base for biogas production (crop residues), consolidation of livestock enterprises and the transition from solid waste disposal to the use of mechanical and biological AD treatment technology. It should be noted that according to the company “Naftogaz of Ukraine”, the total consumption of natural gas in Ukraine was 29.8 bcm in 2019, of which 14.3 bcm (48%) were imported3 . Therefore, the maximum possible exploitation of the available biogas/biomethane potential is one of the tools of ensuring the country's energy security.

Ukraine has a powerful transit gas system, which is connected to the European gas network. The main structural elements of the gas transportation system of Ukraine are main and gas distribution pipelines, gas pumping and gas distribution stations, as well as underground natural gas storage facilities. Europe also has an extensive gas network with a total area of 2.2 million kilometers, to which at least two-thirds of existing European biomethane plants are currently connected. A unified European gas infrastructure and a functioning international gas market model potentially allow biomethane to be traded physically or virtually. Natural gas is one of the main sources of energy for industry and households in Ukraine. About 65% of natural gas consumed in Ukraine is provided by its own resources (20.2 out of 30.9 billion m3 in 2020), the remaining 35% is imported.

That is, the potential opportunities of our country for the cultivation of energy bio-raw materials and the production of biofuels are quite high. The research methodology is based on experimental studies of scientific topics on the topic: «Development of bio-organic technologies for growing agricultural crops for the production of biofuels and ensuring the energy independence of the agricultural sector».

The scientific works of H.M. Kaletnik are devoted to the problems of creating an effective system of cultivation and processing of agrobiomass in modern conditions. [24, 27], Honcharuk I.V., Vovk V.Yu., Pantsyreva G.V. [25, 29], Kaletnik H.M [23, 34], Hontaruk Y.V. [58-61] and others. However, the creation of an effective biomass processing and cultivation system today requires the development of appropriate directions for the development of biofuel production from agricultural products in the conditions of rising energy prices on the world market and the refusal of the supply of hydrocarbons from the aggressor country is extremely necessary, which determines the relevance of this study.

In order to reach the objectives and targets there is a need for having better dialogue between different stakeholders (producers, users, decision makers, official and other). There is big number of different stakeholders, as the biogas sector is strongly involved in different sectors such as energy production, agriculture, transportation and waste management. Biogas is not only about energy production but it also an excellent way to recycle nutrients. Moreover, there is a need for defining long term actions; hence an official national biogas production target for 2035 and long-term national incentive package are urgently needed. The targets and actions agreed together would create confidence in the industry's growth potential for the current players and for newcomers. The Ukrainian biogas sector has already started the journey to call for long term actions by launching a Roadmap for Bioenergy Development in Ukraine until 2050 published in the UABio Position Paper. As estimated by the experts of the UABio production of biogas could be 1.45 Mtoe (17 TWh) in 2035 (fig.1).

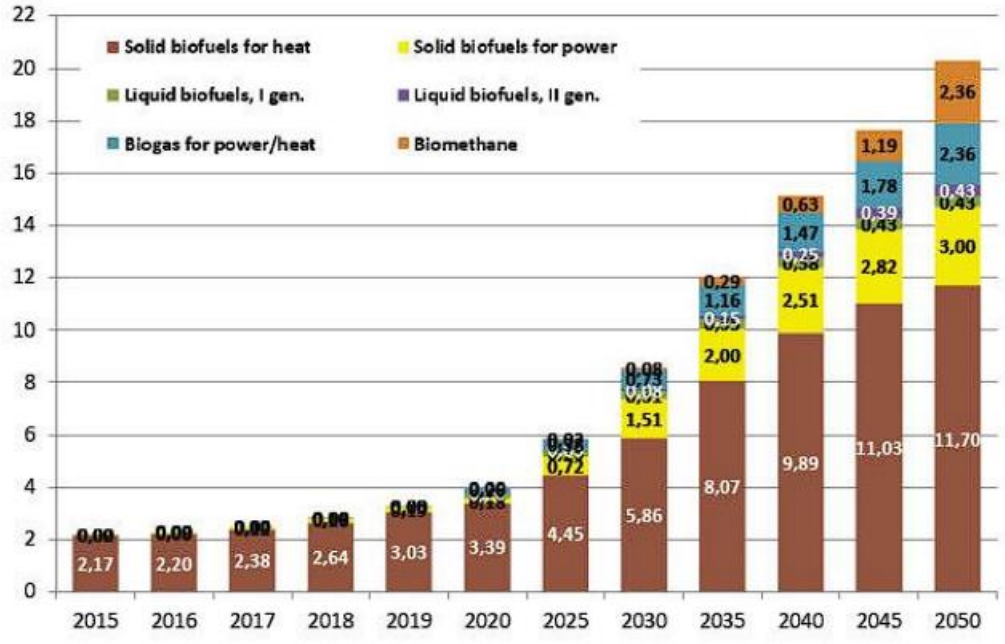

Fig.1. Suggested structure of using biofuels in Ukraine until 2050, by type of energy carrier, Mtoe

Today, Ukraine owns significant areas of land, but their potential, especially in the field of biofuel production, is used to an insignificant extent. In the conditions of the partial destruction of the infrastructure and logistic routes for the export of agricultural products due to the military invasion of Russia, it is necessary to solve the issues of processing agricultural products within the borders of Ukraine. Special attention should be paid to the development of biofuel production in conditions of rising energy prices.As noted by Kaletnik G.M. the total potential of bioenergy production from 10 million hectares of land in the state can amount to more than 28.99 million t.e. Currently, biomethane is obtained to a greater extent by purification and enrichment of biogas produced by biological methods from various types of organic materials. According to the EBA, more than 75% of active biomethane plants use membrane separation (39%), water scrubber (22%), or chemical scrubber (18%) for biogas enrichment. In other cases, pressure swing adsorption (12%), cryogenic separation (1%) and physical scrubber (1%) are used. It should be noted that for 7% of European biomethane plants in the EBA database there is no data on enrichment technology.

Biomethane can be used for power generation, in industry, for heating/cooling and in all types of transport from cars to trucks and marine vessels. It can be produced both for domestic consumption (feeding into the gas network with subsequent use for the production of electricity and/or thermal energy, or as motor fuel for vehicles), and potentially for export to other countries. The production of biogas with enrichment to the quality of biomethane allows it to be supplied to the gas network, easily stored and delivered directly to the consumer. It is known that 47% of biomethane plants currently operating in Europe are connected to the gas distribution network, and 20% to the gas transmission network. In addition, 10% of European biomethane plants are not connected to the grid, and no information is available on the remaining 23%.

In Germany, the main market for the production and consumption of biomethane, 88% of the biomethane produced in 2017 was used for the combined production of electricity and heat, 5% for heating and only about 5% for transport. The use of biomethane in the chemical industry and for export to other European countries played a secondary role in Germany (2%), but had a high development potential. In Denmark, most biomethane is exported to Sweden and Germany. The remainder is used for heating and for industrial purposes (heat of industrial processes and raw materials for the chemical industry). Around 14% of biomethane produced in the EU in 2020 was used as motor fuel in countries such as Italy, Sweden, Germany, Finland and Estonia. The use of biomethane in transport grew at the fastest rate in Italy, where almost all biomethane is used as motor fuel. Italy has already overtaken the former European leader of this business – Sweden in absolute terms. In addition to Italy, according to the EBA, almost the entire volume of biomethane is used in transport in countries such as Finland and Estonia.

Main direction of the biogas energy use is feeding electricity into the power grid. Intensive development of biomethane production projects, followed by injection into the NG network began in the last decade. Usually biomethane fed into the gas distribution network at a pressure below 16 bar. Examples of biomethane injection in high-pressure pipelines or gas storage facilities are not known. In some cases, BM is supplied directly to the gas filling stations for use as a motor fuel. Biomethane production projects are geographically located in Europe, North America (USA, Canada), and the Far Eastern countries: Japan and South Korea (Fig.2).

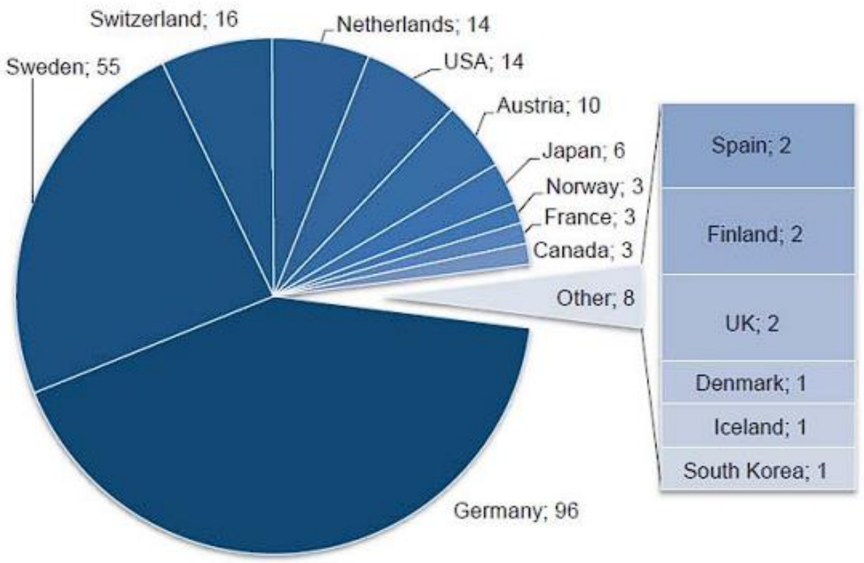

Fig. 2 – Biomethane projects in the world

Currently, BM is produced in 15 European countries4 . Injection of BM in NG grid takes place in 11 countries (Austria, Czech Republic, Germany, Denmark, Finland, France, Luxembourg, Netherlands, Norway, Sweden, UK)5. In 12 European countries (Austria, Czech Republic, Germany, Denmark, Finland, France, Hungary, Iceland, Italy, Netherlands, Sweden, United Kingdom) biomethane used as motor fuel (separately or mixed with NG). Biomethane also used for heat production (also separately or in admixture with NG). To date, the total number of stations in biomethane stations in European countries reached 250 units, of which 200 stations connected to the NG6.

For biogas upgrading to biomethane different technologies are used. Most common is water scrubber technology, as well as pressure swing adsorption (PSA) and chemical scrubber (Fig. 3).

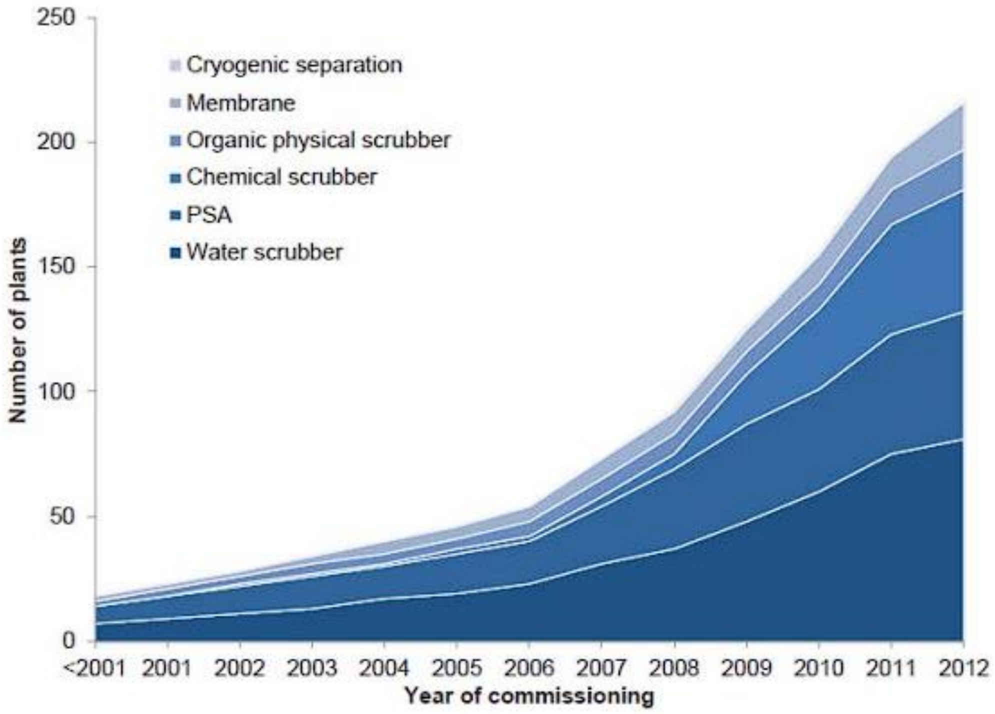

Fig. 3 – Biogas upgrading technology in the world

Total production of BM in 2012 was 0.76 billion m^3 . According to estimates by the European Biogas Association (EBA) annual BM production in the EU could reach 8.9 billion m3 by 2020 and 19.8 billion m3 by 2023. According to the research of three European projects (BIOMASTER, GreenGasGrids and Urban Biogas) biomethane could replace 3% of the total NG consumption or 10% of total consumption of motor fuels in the EU. According to NGVA (Natural and bio Gas Vehicle Association), BM production from 3.5-5.4% of biogas could replace 10% of the total gas consumed as motor fuel or 0.5% of total consumption of motor fuels in the EU. Most dynamically BM production is developing in Germany. The first BM plant began its work in 2006. During the period from 2006 to 2013 the number of BM projects grew up to 169 units. The total BM capacity increased to 900 million m^3 per year (Fig. 3) Most of the projects delivered biomethane into the NG grid, several projects provide gas filling stations. Capacity of the projects varies widely within the country. The biggest projects produce

10,000 m^3 of biomethane per hour (Güstrow, Zőrbig, Schwedt), the smallest projects generate less than 300 m^3 of biomethane per hour. Average BM capacity is around 550-600 m^3 /h.

Overall, in December 2022 in Germany primary energy of biomethane was used mainly for electricity (68%) and heat (31%) production. Natural gas plays a minor role in the transport sector in Germany. Approximately 90,000 vehicles running on the country's natural gas (0.2% of the total leet). For this reason, only a small portion (1%) of BM has found an application as a motor fuel. However the number of gas filling stations is large enough accounting 900 units, although the density of gas filling network smaller than density of liquid fuel stations. There is a trend of the growing of BM use as motor fuel.

Thus, during 2022, the share of biomethane for vehicles increased from 6 to 15% of the total use of gas fuel in the market. German Federal Government has set a target to increase production of BM in 2020 to 6 billion m3 /year and in 2030 up to 10 billion m3 per year. Goals to further increase of BM use as a motor fuel are also announced.

The fulfillment of these objectives will be accompanied by increasing the number of filling stations from 900 to 1300 units and introduction of standards for the use of BM at 20% in the mixture on compressed NG. Sweden is rightly considered as one of the leader in the use of biomethane for transport.

As of 2022, there were 55 biomethane stations (BMS), of which only 11 supplied BM into the NG grid10. Total production of BM was about 135 million m3 per year. With an average annual growth of BM consumption as motor fuel equals 25% the share of BM consumption in Sweden twice exceeded the share of natural gas in 2009/

The prospects for the development of biomethane (BM) production are discussed in this position paper of Bioenergy Association of Ukraine. It is a new direction for Ukrainian renewable energy.

European projects of BM production development The development of BM production in Europe is accompanied and stimulated by European projects, such as:

GreenGasGreeds. GreenGasGrids project supports the upgrading of biogas to biomethane for injection into the natural gas grid; the project involved a consortium of 13 European partner companies, coordinated by the German Energy Agency (dena);

BIOMASTER. Project is supported by 17 partner companies, aims to promote the use of biomethane in transport sector; project is also intended to promote the use of methane in the NG grid;

Urban Biogas. Project is created to promote the use of biomethane in local NG network. The basic idea of the project is to develop projects of the municipal waste treatment with biomethane production in cities of five European countries (Croatia, Portugal, Austria, Poland, and Latvia).

State support is an effective stimulus of BM production. However present support schemes in Europe are mainly aimed at the generation of electricity. At the national level, only a few Member States set specific goals for the production of biomethane and methods of achieving them. Below is a brief description of the mechanisms for stimulating BM production in the leading countries in this field by information published in the repor.

Germany is a leader in the development of biogas technology in Europe. The main raw material for the production of biomethane is maize silage. This is typical for large projects. Manure is typical for small biogas plants producing electricity from biogas. The new German Act on RES, enacted in 2012, limits the proportion of maize silage and crops residuals use for the production of biogas/biomethane is not more than 60%. Simultaneously document stimulates the use of biodegradable household and industrial waste as well as pasture grasses.

German law supports coproduction of heat and electricity, so most of the produced BM used by CHPs.

Requirements for connection to the gas network (GasNZV) describe the general conditions of access for biomethane plants, in particular:

Procedures - how to submit and execute requests for grid connection.

The dividing of responsibility and connection costs.

Regulation of methane leaks.

Providing a special bonus for non-use of main pipelines, equal 0,7 €cent/kWh.

In general, the document defines the basic cost-sharing between the producer and the owner of NG network (25%/75%). If the distance between the biomethane station and the point of connection to the grid is less than one kilometer, the cost for BM producer is limited by €250,000. If the distance is more than 10 kilometers, the costs are fully covered by the producer.

Connection point is the property of the grid owner. The cost of its operation, the pressure rise, odourization, monitoring and possible correction of BM calorific value are covered by the owner. The owner is required to ensure the 96% technical readiness of the connection point for the year. Requirements for BM quality are described in the technical standards DVGW G260 and G262. Standards include two possibilities for BM injection - as an additional gas, and as a substitute of NG. In the first case the gas mixture in the pipeline must comply with the technical requirements, so the network can accept different quality of biomethane, especially in large pipelines.

Demand for biomethane Germany is formed by the following factors:

Fixed tariff for renewable electricity.

Commitments for production of renewable heat.

Commitments for production of renewable motor fuel.

Producers of renewable energy in Germany are guaranteed in access to the electricity grid and a fixed tariff rate for 20 years. Production of electric energy from biomass can qualify for a fixed rate only in case of heat use (CHP).

All buildings constructed in Germany after 01/01/2009 must use renewable energy for heating. In the case of BM at CHP a share of renewable fuels must be at least 30%. Since 2007, all suppliers of motor fuels must use a certain percentage of biofuels in petrol and diesel fuels. In 2009, biomethane has got equal rights with liquid biofuels. In the case of noncompliance, for example, the owner of the gas station has to pay fines. Conversely, an excess of liabilities can be sold on the market.

To participate in the support schemes biomethane producers and consumers should confirm the source of its origin and compliance with certain criteria. For this purpose, the Agency dena has developed German biogas register, introduced in 2011.

Register defines BM standards and allows manufacturers, retailers and consumers to document the type of biomethane. According dena market accepts a documentation system and most of the produced biomethane goes throw the register. Sweden is a pioneer of upgrading of biogas to biomethane, developing this technology over the last twenty years.

Most of biomethane in Sweden is used as motor fuel. Approximately half of the Swedish biomethane plants works based on wastewater treatment plants. The rest uses MSW and agriculture waste for biomethane production. Sweden has a significant potential of bio-SNG production from forest residuals, so the government supports gasification research projects, the most famous of which is the project in Gothenburg (GoBiGas) for the production of biomethane with capacity 80 MW (8000 m3 /h of BM).

According to the decision of Parliament contribution of RES in final energy consumption should reach 50% in 2020. This goal has been achieved already in 2012. Sweden is considering the full transition to renewable energy sources by 2050. It is assumed that in 2030 the transport sector will not be dependent on fossil fuels. Sweden has developed network of natural gas supply.

In Switzerland biomethane use as a vehicle fuel is encouraging. The mixture of NG and BM are sold at gas filling stations branded "Naturgas" or "Kompogas". Many local companies offer biogas to private consumers for heating purposes. In 2011, the Parliament adopted the decision to abandon nuclear energy development and decommissioning of spent nuclear units until 2030.

As a result of this decision the policy on renewable energy was changed. In particular, biogas/biomethane is regarded as an important component of energy supply. Biomethane production is supported by a special biogas fund whose objective is a 6 time increase in the production of biomethane for 6 years.

The country provides equal opportunities for access to the gas network for all types of biogas. The Standard G13-09 defines the requirements for gas quality. The Standards G11 and G209 define the procedure of odorisation and technical solution to connect to the network. The possibility of mixing biomethane with propane or LPG for correction of calorific value is also described. In Switzerland, advanced system of fixed tariffs for electricity produced from biogas/ biomethane is implemented.

The basic rate is between 14.6 to 23,3 €cents/kWh. There are requirements for minimal performance, as well as additional bonuses for heat utilization. Biogas plant using agrarian waste and no more than 20% of additional substrates (energy crops or organic waste) may receive an additional bonus 3.7 €cents/kWh with installed capacity of less than 5 MW and 15 €cents/kWh with installed capacity less than 50 kW. Upgrading of biogas to biomethane is not accompanied by additional bonuses. Fixed tariffs are guaranteed for 20 years.

In the Netherlands, the network is permitted for injection of BM derived from any type of biogas. One of the conditions is the lack of pathogens in biomethane. It is mandatory the use of HEPA filters and fulfillment of monitoring (at least two times per year).

Calorific value of NG in the Netherlands is lower than in other countries. Accordingly methane content requirements are less stringent. Production of renewable energy in the Netherlands is stimulated by a special scheme SDE +, which provides subsidies to cover the difference between production costs and energy prices. There were five categories of subsidies ranging from 0,483 to 1,035 €/m^3 in 2012. Tariffs are guaranteed for 12 years, but may be adjusted annually according to the market price of NG. The country adopted national obligation for the use of motor biofuels of 10% in 2020, which also applicable to gas biofuels. Control scheme for sustainable production of biofuels is developed and implemented. The system of certification of production and consumption of BM and the raw materials used to its production was completed in 2019.

In Austria, the Gas Act (GWG) describes the framework conditions of injection of biomethane into the gas network. Act ensures nondiscrimination and priorities for gases of biological origin. Operators of gas distribution networks are required to define the technical conditions for connection, and the connection cost should be borne by BM supplier. Requirements for biomethane quality are described in detail in the directives ÖVGW G31 and G33 and rigidly adhered to the quality of NG. In addition to the injection process odorisation requirements must be fulfilled in accordance with Directive ÖVGW G79.

Support of biomethane production in Austria can be implemented by two mechanisms - providing federal grants and exemption of biomethane from fossil fuels tax. Grant size can reach 25% of the investments cost. Grant does not depend on the project size, the raw materials used or BM utilization option. Additionally, a bonus of 5% may be given in the case of meeting of sustainability criteria (reducing greenhouse gas emissions by 45%). In the UK about 360 biogas plants were built, mainly in wastewater treatment plants. Biogas plants work also in agriculture. National strategy is focused on the processing of biodegradable waste, the use of energy crops for biogas production is limited. Currently there are two installations for the production of biomethane launched in 2010. Both projects are connected to the gas network.

Unlike other forms of renewable energy, electricity tariffs from biogas/biomethane not revised downward. It is believed that the decrease in technology costs is compensated by the increased cost of raw materials for the production of biogas. In the case of biomethane use as motor fuel special tariffs is not applied, however, BM may be exempted from paying fossil fuels tax. This takes into account technology and type of substrates, the degree of GHG emissions reduction, the risk of biomethane leakages.

The first terminal for liquefied natural gas (LNG) was built in May 2011. Using LNG is considered as a link between natural gas and biomethane/biogas required until the possibility of using liquefied biomethane / biogas (LBG) will be developed. Biomethane in transportation sector has been used since 1996. The market share of the compressed NG for transport has risen steadily, and the use of biomethane increased overtaking pace. Approximately 15% of buses in Sweden running on biogas, and the proportion of new buses on biogas reaches one-third. At the city level different incentive mechanisms are used like exemption from payment for entrance into the city, special lanes for BM taxi, free parking for BM car.

The opportunity, the importance of expediency as well as recommendations for the development of production and use of biomethane in Ukraine are shown.

Biomethane under normal conditions is a gaseous fuel with a calorific value close to natural gas (NG) (35 MJ/nm^3). To date, biomethane is mainly obtained by purification and enrichment of biogas produced by biochemical methods from different types of organic materials. Biomethane production is growing rapidly in the EU and has a good preconditions and prospects in Ukraine, namely:

1. High energy intensity of the economy of Ukraine in comparison with world figures. Unreasonably large consumption of natural gas, including the needs of backward industrial enterprises.

2. Critical Ukraine's dependence on gas supplies from unstable foreign markets, including Russia.

3. High and volatile natural gas prices, upward trend for all categories of consumers.

4. Great potential for biogas production from agricultural waste (3.2 billion m^3 CH4 per year).

5. Large potential of biogas/biomethane production (3.3 billion m^3 CH_4 per year) using available arable fertile land for energy crops cultivation and their potentially lower cost (compared to the production in western countries).

6. Presence of significant number of big agricultural enterprises with financial and land potential for the development of major projects for biomethane production.

7. Presence of the developed NG transport infrastructure, including both pipelines connecting Ukraine with European countries, and local network of distribution pipelines, providing greater part of the population of Ukraine with natural gas.

8. Tradition of NG using as motor fuel for vehicles, well-developed network of vehicles gas filling compressor stations (VGFCS1).

Biomethane can be produced for both domestic consumption (feed gas distribution network, followed by use for electricity and/or thermal energy, or use as vehicles fuel) and for export (by main gas pipelines, road and railway transport or sea).

Currently in Ukraine there are no examples of biomethane production projects, as there is no legal and regulatory framework for its use. Given the prospect of this trend in the current environment of Ukraine, presented in this paper, the material could be useful and relevant to policy and investment decisions.

Today, Ukraine owns significant areas of land, but their potential, especially in the field of biofuel production, is used to an insignificant extent. In the conditions of the partial destruction of the infrastructure and logistic routes for the export of agricultural products due to the military invasion of the Russian Federation, it is necessary to resolve the issues of processing agricultural products within the borders of Ukraine. Special attention should be paid to the development of biofuel production in conditions of rising energy prices.

As noted by Kaletnik G.M. the total potential of bioenergy production from 10 million hectares of land in the state can amount to more than 28.99 million t.e. (Table 1).

Without a threat to food security and the export potential of the state, about 10 million hectares of agricultural land can be used for growing energy crops with their subsequent processing into biofuels, in order to ensure the energy independence of the agro-industrial complex and Ukraine. That is, the potential opportunities of our country for the cultivation of energy bio-raw materials and the production of biofuels are quite high [1].

Table 1. Calculation of bioenergy production in Ukraine taking into account changes in the latest technologies and crop rotation

Crops	Area growing	Crop capacity, t/ha	Fuel yield from 1 ton of raw material	Fuel yield, from 1 t Raw materials *	Fuel output, i.e. from 1 t of raw material*	Fuel output from 1 ha, soot*	Entrance fuel of all million so-called
Bioethanol							
Sugary beets	1,5 million hectares	60,0	100 l	0,079 t	0,051	3,06	4,59
Corn	1,5 million hectares	7,0	416 l	0,329 t	0,211	1,48	2,22
Wheat	1,0 million hectares	5,0	395 l	0,312 t	0,20	1	1
Biodiesel							
Turnip	2,0 million hectares	2,5	420	0,36 t	0,31	0,78	1,56
Soybean	1,0 million hectares	2,2	200	0,17t	0,15	0,33	0,33

Continuation of table 1

Biogas							
Silage corn	2,0 million hectares	40	180 m^3	-	0,15	6	12
Pulp sugar beets	Sugar beet cultivation area (1.5 million hectares)	19	120 m^3	-	0,08	1,52	2,28
Solid biofuel							
Energetic poplar, energy willow	0,5 million hectares	14 dry matter	-	-	0,43	6,02	3,01
Miscanthus, switchgrass	0,5 million hectares	10 dry matter	-	-	0,4	4,0	2,0
The total potential of bioenergy production from 10 million ha, million t.e.							28,99

1 liter of bioethanol – 0.79 kg; 1 liter of biodiesel – 0.86 kg; 1 ton of bioethanol – 0.64 t.e.; 1 ton of biodiesel – 0.86 t.e.; 1 thousand m3 of biogas –0.812 t.e.

Source: [61]

Special attention should be paid to the development of biofuel production in conditions of rising energy prices. However, it should be noted that today the potential of agricultural crop waste in the form of straw and waste from oil refineries is used to a small extent, which can significantly increase the production of solid biofuel in the short term.

In the conditions of refusal to import energy carriers from the Russian Federation, the supply routes from the EU countries are being adjusted today. However, the purchase of natural gas and gas oils in conditions of rising prices on the EU market is quite expensive, so it is necessary to develop directions for improving the cultivation and production of agrobiomass for biofuel, including biogas and biodiesel.

In the conditions of refusal to import energy carriers from the Russian Federation, the supply routes from the EU countries are being adjusted today. Currently, on the basis of the research and production capacities of NNVK "All-Ukrainian Scientific and Educational Consortium" of the research and production laboratory focused on improving the cultivation of agrobiomass and the provision of services for the processing of energy crops into biodiesel and the creation of prototypes of installations for the production of biogas by private peasant farms.

According to Honcharuk Inna, the main obstacles to the development of biofuel production are the following:

– in most cases, it is not economically profitable for farms to produce biofuel, preference is given to exporting raw materials;

– lack of financial incentives for the implementation of bioenergy projects;

– high level of risks for potential investors;

– shortage of own funds of Ukrainian companies, their low financial capacity and high cost of bank lending;

– insufficient financing of scientific research and introduction of new technologies [3].

Biogas after reactor or landfill has a relative humidity of 100%. Water vapor content depends on temperature and equals 40 g/nm3 at 35o C. A typical way of removing moisture from the biogas is vapor condensation at low temperatures. To raise the temperature of "dew point" before cooling further increases the pressure of biogas. In case of biomethane use as motor fuel "dew point" should be below -40°C under a pressure of 4 bar. In this case, further water vapor adsorption on the surface of a drying agent (silica or alumina) is used. The adsorption is carried out at overpressure, after which the drying agent is regenerated when the pressure decreases. Another way to reduce "dew point" may be the absorption of water in the glycol or hygroscopic salts. Desorption of the water occurs at higher temperatures. Salt should be replaced.

The raw material base for the production of biomethane can include a wide list of types of organic materials. In general, 12 separate categories of raw materials can be distinguished, as shown in the table. 2.

Table 2. Categories of types of raw materials suitable for biogas production

№	Category	Objects of collection of raw materials	Examples of raw materials
1.	Livestock manure waste	- cattle farms (dairy farms) - pig farms - poultry farms - MRKH farms, other farms	- litter manure - liquid manure - litter
2.	Crop residues	- plant breeding enterprises	- grain straw (primarily wheat) - stalks and ears of corn - sunflower stalks and baskets - beet pulp
3.	By-products and waste of the food processing industry	- sugar factories - distilleries - breweries - starch and molasses production - flour and grain mills - oil extraction plants - meat processing plants - slaughterhouses - canneries - winemaking enterprises - other productions	- beet pulp - molasses (molasses) - a grain of beer - alcohol bard (grain, post-meal) - fruit juices and waste - squeezes and vegetable waste - grape juice - oily cake and fudge - sunflower husks - cereal husks - chaff, bran and other grain waste - by-products of animal origin
4.	Bioethanol and biodiesel production waste	- bioethanol plants - biodiesel plants	- alcohol bard - Rapeseed meal/cake - glycerin
5.	Energy crops	- plant breeding enterprises	- corn for silage - sorghum for silage - piercing-leaved sylphium - sugar beet - winter rye
6.	Phytobiomass of water bodies	- natural water bodies - artificial water objects and systems	- higher aquatic vegetation - microalgae
7.	Horticulture waste	- communal park farms - airports - large sports grounds with a natural surface	- mowed grass from lawns - fallen leaves
8.	Trade and public catering waste	- communal and private catering establishments - food markets and shops	- remnants of ready-made food - substandard food products - food residues and waste - used oil

Continuation of table 2

9.	Solid household waste	- waste sorting stations - enterprises of complex mechano-biological processing of solid waste - garbage cans with separate collection of organic waste	- organic fraction of MSW
10.	Wastewater and its sediments	- city sewage treatment plants - local sewage treatment plants of industrial enterprises	- primary sediments of aeration stations - secondary sediments (activated sludge) of aeration stations - fat flotoshlami - highly concentrated industrial wastewater
11.	Cover crops (green fertilizers)	- plant breeding enterprises	- shout - rye - turnip / radish - legumes - clover, others
12.	Vegetation of meadows	natural meadows that are not used for farming and that are not included in the nature reserve fund	- multi-species perennial grass cut from meadows

From the point of view of raw material sustainability, the first priority in the production of biomethane should be given to wastes that by their nature have no other alternative use than final disposal, incineration, conversion to energy or use as organic fertilizers or soil improvers. These types include, for example, manure waste, substandard food products, the organic fraction of MSW, sewage sludge, grass clippings from artificial lawns, by-products of animal origin that are not suitable for human consumption, etc.

The expediency and potential scale of involving certain types of raw materials for the production of biomethane is determined by a number of factors. Among the main factors of influence are the specific cost of a unit of energy in raw materials, taking into account delivery to the biogas station (UAH/MJ), the level of technological complexity of processing into biogas, availability within a reasonable delivery radius.

When producing biomethane for export to countries where systems of guaranteeing the origin of renewable biofuels have been implemented in transport, the type of raw material from which it will be produced can affect the contract price for biomethane. In this case, it will be appropriate to use those types of organic materials, which, according to the approved lists, are set for 2-fold crediting of the produced energy. At the EU level, such a list of materials is provided in Annex IX of the EU RED II Directive [24].

From the point of view of raw material sustainability, the first priority in the production of biomethane should be given to wastes that by their nature have no other alternative use than final disposal, incineration, conversion to energy or use as organic fertilizers or soil improvers. These types include, for example, manure waste, substandard food products, the organic fraction of MSW, sewage sludge, grass clippings from artificial lawns, byproducts of animal origin that are not suitable for human consumption.

The same list also includes harvest residues of agricultural crops that are not used for animal feed, for example, cereal straw, corn stalks.One of the promising types of raw materials for biogas, which does not compete with food products and fodder, are cover crops [25], which are grown in the interval between two annual food crops. The use of the collected mass of such crops for biogas, with the subsequent return of the digestate to the same fields, allows to significantly expand the potential of attracting arable land resources to the energy sector without harming agricultural production. According to EVA [26], more than a quarter of the biomethane production potential can be ensured by using cover crops for this purpose.

Next, priority should be given to by-products of various industries, which have either lost their commercial properties for alternative use, or for which there is currently no alternative demand in a certain place as food or animal feed. The list of such products can include, for example, sugar beet pulp, grain processing waste, fuzz and meal of oil crops, etc.

The use of specially grown energy crops for the production of biomethane in the EU countries is given less and less priority. Starting from 2018, no new biomethane plants were built in Europe, the main raw material for which would be corn silage. Therefore, when producing biomethane in Ukraine for export from corn silage, it should be borne in mind that the contract price for it may be limited.

However, the use of corn silage for biomethane in the current conditions of Ukraine can still be considered as a technologically and economically feasible option, at least for domestic consumption. UABIO's position is that the further increase in the use of corn silage for biogas in Ukraine will not lead to significant competition with food products and animal feed within the country for quite some time. Therefore, stricter climate requirements and issues of ensuring the sustainability of food chains, which have recently been introduced in the EU countries, could be postponed or softened for Ukraine. This is especially relevant in light of the critical need to diversify the supply of energy resources, both in the EU and in Ukraine. But at the same time, it is necessary to take into account the important role of Ukraine as a grain exporter to ensure the food security of some countries in Asia and Africa.

Among the arguments regarding the expediency of further use of corn silage for biogas in Ukraine, the following can be cited:

1. Ukraine has one of the largest areas of arable land in the world. According to this indicator, Ukraine ranks first among the countries of Europe and 8th among the countries of the world.

2. Ukraine has one of the largest specific arable land areas in the world, per 1 inhabitant – 0.74 ha/person [27,28]. According to this indicator, Ukraine ranks 3rd among the countries of Europe (after Lithuania and Latvia) and 7th among the countries of the world.

3. In Ukraine, compared to individual EU countries, the use of corn silage for biogas is incomparably smaller. So, for example, in Germany as early as 2012, about 1 million hectares were used for growing corn for silage for biogas, which was 8.3% of the total arable land area of 11.57 million hectares [29]. In 2019, the total use of land resources for the cultivation of raw materials for biogas in Germany was 1.55 million hectares, and the total for all types of energy crops was 2.67 million hectares [30]. According to UABIO, in Ukraine in 2020 corn silage for biogas was grown on an area of 14,000-20,000 hectares, which is only 0.4-0.6% of the total arable land area.

4. There is a significant potential to increase the productivity of the main food and feed crops in Ukraine, and hence the possibility of increasing the share of land for

energy use while maintaining the current level of gross production of the main food and feed crops.

In Ukraine, the list of raw materials used for biogas production is limited to 5 main types, namely: pig manure, cattle manure, chicken manure, sugar beet pulp and corn silage. According to UABIO, the total consumption of these types of raw materials is about 97% by fresh weight (Fig. 4), and the total share of produced biogas from them is about 92% (Fig. 5).

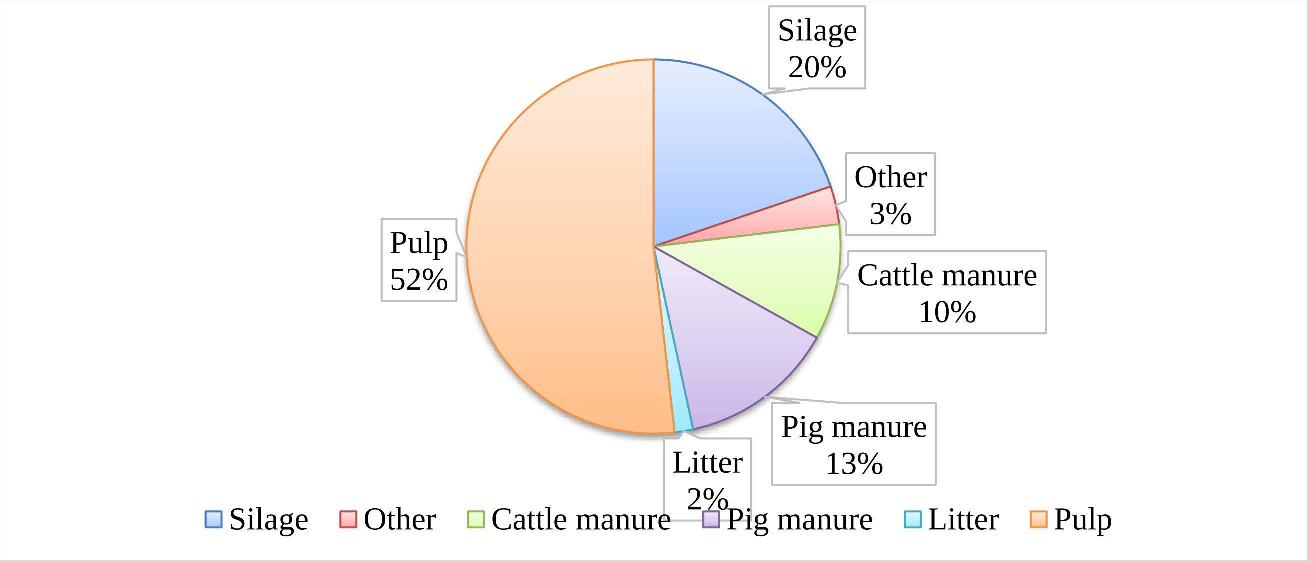

Fig. 4 – Structure of consumption of fresh mass of raw materials for biogas production, 2021

The largest volume of biogas is currently produced from sugar beet pulp (39.8%) and corn silage (38.4%). Grain chaff, molasses, fatty flotation sludge and some other types of raw materials are also used in relatively small quantitie.

Recently, there are examples of the use of cereal straw and corn stalks, which is a promising direction. There are also examples of biogas production from waste water of industrial enterprises (waste water from the production of chips, yeast, beer, cardboard). Sludge from municipal sewage treatment plants is partially used only at the Bortnitsa aeration station, although biogas production projects are also being developed at a number of other large aeration stations (for example, KOS in Kharkiv

and Lviv). Currently, there are still no examples of using the organic fraction of solid household waste for the production of biogas or biomethane.

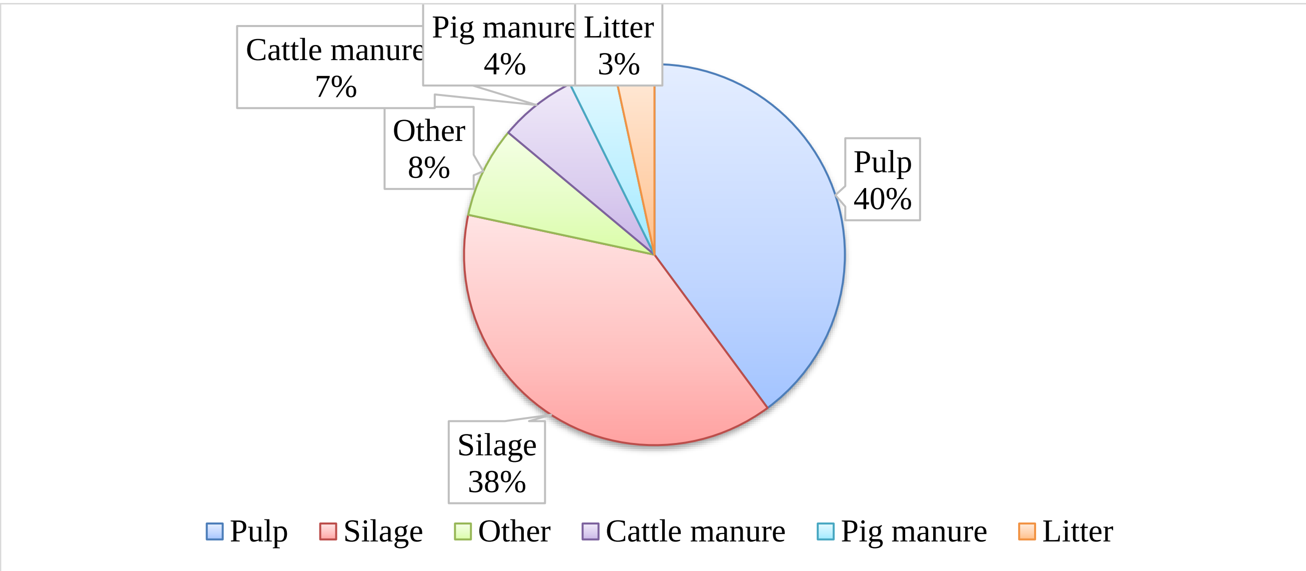

Fig. 5 – Structure of biogas production volumes by types of raw materials, 2021

Recently, there are examples of the use of cereal straw and corn stalks, which is a promising direction. There are also examples of biogas production from waste water of industrial enterprises (waste water from the production of chips, yeast, beer, cardboard). Sludge from municipal sewage treatment plants is partially used only at the Bortnitsa aeration station, although biogas production projects are also being developed at a number of other large aeration stations (for example, KOS in Kharkiv and Lviv). Currently, there are still no examples of using the organic fraction of solid household waste for the production of biogas or biomethane.

According to UABIO, the total potential of cattle manure is used for approximately 4%, pig manure for 6%, manure for 1%, pulp for 20%. The use of the potential of other types of raw materials for biogas production does not exceed 1-2%, and most types are still not used at all. Thus, there is a fairly significant potential to increase the use of almost all types of raw materials for the production of biogas and biomethane.

Considering the negative foreign trade balance of the state and the significant potential of Ukraine in the agricultural sector, the situation can be corrected by focusing on the production of biogas from the waste of the state's agricultural industry. One of the key producers of biogas can be sugar factories that have undergone production restructuring due to the creation of biogas production facilities. One of the key producers of biogas can be sugar factories that have undergone production restructuring.

Research by Tokarchuk Dina show that 1 ton of molasses can be obtained up to – 630 m^3 of biogas, beet pulp – 170 m^3, bard – 45 m^3 (Table 3).

Table 3. Biogas output from certain types of agricultural products

Raw	Biogas output, m^3
Molasses	630
Beet pulp	170
Barda	45

Source: Generated from data [53]

According to the results of 2021, 68 industrial biogas plants were built and put into operation in Ukraine, the total capacity of the industry reached 105 MW, and the total gas production reached 230 million m^3.

Based on numerous studies, the implementation of the program «Road map for the development of bioenergy in Ukraine until 2050 and the Action Plan until 2025» should be supplemented by the following measures regarding the state stimulation of owners and tenants of land plots to use biofuel production technologies:

- preferential lending for the purchase of equipment for the production of biofuels;

- granting the right of priority lease of state agricultural land for enterprises and farmers focused on the production of biofuels;

- provision of state subsidies for in-depth scientific research in the field of biofuel production to research institutions [10, 56].

Appropriate steps will make it possible to carry out the necessary modernization of agro-industrial complex enterprises, including sugar factories. The impetus for the development of biogas production with subsequent conversion into biomethane is the future increase in taxes in the EU countries on the import of products that were produced using «dirty» energy. Thus, in the European Union, starting from 2023, a tax on the import of products that will be produced using «dirty» fossil fuels will begin to apply. This is especially relevant for metallurgical plants. If metallurgical plants will not use fossil gas or coal in their production, but biomethane, this will make it possible to make their products more competitive on the market. In the short term, the main part of the produced biomethane will be sent for export to the EU countries where much more favorable conditions for its consumption have been created. Given the existing growth trends of the Ukrainian economy, it is possible to predict an increase in the consumption of produced biomethane in Ukraine.

With the complete processing of by-products of sugar factories, based on the capacities of 2021, it is possible to obtain almost 790 million m^3, which in terms of biomethane is 473.7 million m^3. This will make it possible to reduce the volume of natural gas imports and provide sugar factories with their own energy carriers, which will positively affect the cost of sugar production (Table 4).

Table 4. Potential volume of biogas production from by-products of sugar factories

Raw	The volume of raw materials (2021 level), thousand tons	Potential volume of biogas production, million m^3	In terms of biomethane, million m^3
Molasses obtained during the extraction or refining of sugar (except cane)	268,0	168,84	101,3
Beet pulp, bagasse (sugar cane pulp), other sugar production waste (including defecation sludge)	3650,6	620,6	372,4
Total, million m^3	X	789,44	473,7

Source: own research

It should be noted that at biogas plants that can be created on the basis of sugar factories, it is possible to process other agricultural products, namely straw, cattle manure, bard, etc. This will make it possible to fully ensure the potential capacity of biogas plants. Also, the production of biogas will make it possible to avoid the pollution of water resources by sugar production waste. The by-product of biogas production – digestate is a valuable fertilizer and can be sold to agricultural enterprises. Therefore, in addition to the processing of by-products of sugar production, the relevant biogas plants on their basis can solve problems with the disposal of animal husbandry waste.Utilization of agricultural waste, namely livestock waste by processing it into biogas, is an important aspect not only of the environmental friendliness of this process, but also contains an energy component – ensuring energy independence, i.e. the use of one's own renewable raw material base and rejection of fossil energy carriers or imports, diversification of energy supply. However, the economic benefits from the use of biogas in each specific case will depend on the type of waste available for processing, investment opportunities, the presence of a local energy market and government initiatives [11, 33].

Therefore, sugar factories can achieve the greatest efficiency by creating biogas plants on their own material and technical base, focused on processing their own by-products and agricultural waste.

The assessment of the energy potential of biomethane production in Ukraine is based on the analysis of the current (2020) level of production of main crops by agricultural enterprises, products of the food processing industry, the available livestock of cattle, livestock, pigs and poultry at livestock enterprises, as well as the volume of solid household waste generation and wastewater in the communal economy. The types of raw materials taken into account in the assessment of the potential, as well as the taken into account shares of the total mass for the production of biomethane are shown in fig. 6.

There are two basic concepts of biomethane production projects from biogas. The first concept envisages the construction of a new complex for the production of biomethane «from scratch», including a biogas plant and a biogas enrichment plant.

Livestock manure waste		1) Livestock at enterprises 2) Technically available mass of manure/excrement
Corn silage		1) 1.5:1 by weight to the weight of available manure/excrement 2) Total in Ukraine – 1.1 million ha at 21.8 t/ha
Harvest residues		1) Gross production by enterprises 2) 40-50% of technically available crop residues 3) 90% of technically available botvina
By-products of the food industry		1) Gross production of products 2) 25-75% of the technically available mass
Sewage deposits		1) Wastewater that has undergone biological treatment at sewage treatment plants
Solid household waste		1) Based on the specific generation and fractional composition of household waste in Ukraine (75%)

Fig.6. – Types of raw materials taken into account in the assessment of biomethane production potential

The second concept involves the full or partial repurposing of existing biogas plants from the production of electricity and/or thermal energy to the production of biomethane, with the completion of a biogas enrichment plant and, if necessary, the reconstruction of the biogas plant. The basic concept that will allow for a fairly rapid increase in the volume of biomethane production in Ukraine is, of course, concept 1. However, taking into account the presence of 68 already built biogas plants (as of the end of 2020), which produced a total of about 125 million m^3 of CH4/year [4, 34], as well as chronic problems with payments under the current "green" tariff in Ukraine, concept 2 also has the right to life.

The development of biomethane production in Ukraine will make it possible to:

- reduce the volume of natural gas imports and partially realize surpluses on the energy market;

- give impetus to the development of high-tech production of equipment for biogas plants;

- create additional jobs at bioenergy enterprises;

- to provide agricultural producers with organic fertilizers (digestate);

- to reduce the cost of biomethane production in the case of using the developed scheme of functioning of the production bioenergy cluster.

At the same time, biogas production in Ukraine will be able to provide the following effects for the economy:

- increase the energy independence of the state;

- reduce energy costs;

- to improve the ecological condition of water resources in the region;

- to reduce the volume of greenhouse gas emissions;

- to provide agricultural producers with digestate.

A restraining factor for the development of biomethane production is the high cost of modernization. However, through the use of state grants, subsidies aimed at the creation of biomethane production and increasing fines for CO_2 emissions, it is possible to increase the production of this type of biofuel in the short term.

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2. The bioenergy potential of Ukraine's agriculture to ensure energy independence of the complex

Climate change, increasing use of non-renewable energy sources and environmental pollution are becoming global challenges for humanity. In this context, the use of agrobiomass as an alternative source of energy and a way to ensure environmental and energy independence of enterprises of the agro-industrial complex acquires great importance. Agrobiomass, which includes plant residues, wood, animal waste and other organic materials, can provide a source of sustainable and renewable energy, as well as reduce waste and negative environmental impact. However, achieving this perspective requires serious research, implementation of the latest technologies, and joint efforts from the government, scientific institutions, and agribusiness enterprises. This scientific study will analyze the potential of using agrobiomass to ensure the environmental and energy independence of agro-industrial complex enterprises, and strategies for implementing this direction in practice will also be proposed.

Renewable energy is one of the most discussed topics in Europe and around the world, as the main renewable energy sources are expected to be exhausted within 40-50 years. Mass emissions of carbon dioxide and methane into the atmosphere lead to an increase in the greenhouse effect. Investment in the development of renewable energy technologies such as solar, wind, water, biomass (organic matter of animal or plant origin) or geothermal energy is an urgent need. First of all, the issue of diversification of energy sources is a problem faced by countries such as Ukraine, which import combustible raw materials. It does not have sufficient fuel and energy resources and is directly dependent on importers. Importers supply up to 30% of our natural gas needs and 85% of our oil and petroleum products, setting prices that are rising year after year. Since domestic agricultural enterprises are important consumers of fuel and energy resources, they have an objective need to introduce innovative energy-saving technologies focused on the production of biofuels.

Bioenergy resources are biomass, which, according to the Law of Ukraine "On

Alternative Fuels", is a biologically renewable substance of organic origin that undergoes biological decomposition (waste from agriculture (plant and animal husbandry), forestry and technologically related industries , as well as the organic part of industrial and household waste.

In the conditions of the global financial and economic crisis, which is manifested by the rapid increase in prices for traditional energy carriers, the intensity of irrational consumption of fossil fuels and a number of social and environmental problems, new world views regarding the development and popularization of renewable energy sources are being formed. In many countries of the world, renewable energy resources are considered as an important tool for ensuring the economic growth of countries. After all, not only the level of national security, but also its economic component depends on the degree of provision of energy resources. The need to use renewable energy sources is also due to a number of environmental problems associated with the irrational use of natural resources and emissions of greenhouse gases, which have an anthropogenic impact on the environment and provoke global warming.

Today, in the world, bioenergy is a sector of renewable energy that develops at the most dynamic pace and partially replaces traditional types of fuel in many countries of the world. Taking into account the energy dependence of Ukraine on the import of traditional energy carriers, the development of bioenergy, as a direction of renewable energy, takes on an urgent importance. Implementation of energy and environmental priorities regarding the development of bioenergy can be one of the important means of strengthening the country's energy security.

According to scientists' calculations, Ukraine has a fairly large biomass potential, which amounts to almost 30 million t.p.a. for a year. The use of this potential for energy purposes is capable of reducing greenhouse gas emissions to 11 million tons per year, as well as replacing about 6 billion m3 of natural gas per year in Ukraine by 2027. However, currently the bioenergy sector in Ukraine is developing rather slowly.

For a deeper disclosure of the content of the studied concept, it is important to define the categories "bioenergetics" and "potential". Researchers from different fields of science interpret the concept of "bioenergetics" in different ways. So, in the ecological sense, bioenergy is understood as the use of biomass energy (organic matter, which is formed due to photosynthesis).

In our opinion, it is appropriate to consider bioenergy as a new branch of the economy, which connects solving the problems of obtaining fuel from biomass and environmental protection. In the technical sense, bioenergy is considered as a branch of energy, which is based on the production of energy sources from biomass due to its technical processing.

These interpretations are quite general and do not fully reveal the essence of the "bioenergy potential" category. Thus, taking into account the complexity and multifaceted interpretations of this term, a rather important stage of research is the systematization of scientists' approaches to this issue. Thus, in the 1980s, scientists conducted a study on the classification features of the concept of "potential". The research results showed that in 42% of cases the concept of "potential" is associated with a set of natural conditions and resources, opportunities, stocks, means, values; in 18% - with production capacity, funds, resources; in 16% – with resource, economic, natural characteristics; in 8% - with the possibility of production forces to achieve a certain effect.

In modern economic science, the concept of "potential" is considered from a resource, structural and effective point of view. The analysis of scientific publications makes it possible to conclude that supporters of the resource approach equate the concept of "potential" with "resources". Dubinina M.V. believes that the concept of energy potential should be considered as a set of natural resources and factors of the natural environment of the territory, which can be used in the economy, taking into account the achievements of scientific and technical progress for the purpose of obtaining energy, as well as the mechanisms of their involvement in economic circulation in modern times and in the future to achieve the set goals.

Proponents of the resource approach consider the potential as a set of resources that are necessary for the development and functioning of the system.

A disadvantage of this approach can be considered to be the failure to take into account the possible interrelationships of resources that arise directly in the system itself. Only the actual availability of resources does not give the subject potential opportunities to achieve goals. However, it should be emphasized that the resource approach prevails in relation to the definition of "bioenergy potential". A number of scientists equate bioenergy potential with biomass potential.

In the EU, biomass is considered as biodegraded fractions of products, waste and residues of agriculture (plant and animal), forestry and industries close to them (carbon-containing organic substances of plant and animal origin: wood, straw, plant residues of agricultural production, manure, etc.).

Biomass belongs to renewable energy sources that are powerful in terms of volume, diverse in purpose and use of technologies. It should be noted that types of biomass differ from each other in terms of both chemical and physical characteristics, have a wide range of applications, which is determined by the variety of types of fuel obtained from it. The source of biomass can be agricultural crops that have a high calorific value, perennial plants, as well as agricultural and forestry waste.

Biomass energy can be used to produce electricity, thermal energy, liquid fuels (ethanol, biodiesel), synthetic and biological gas. For each type of bioenergy resources, separate technologies are used for energy production. Therefore, taking into account the above, it should be noted that biomass without technical processing is only a resource, because the energy potential is estimated through the indicators of electricity and gas and heat supply.

According to the alternative production technology, thermal and electrical energy from biomass is realized in two stages: the first stage is the conversion of biomass into new fuel and the second stage is the burning of new fuel in modern power plants.

Technical and technological resources, due to which biomass is transformed into bioenergy potential, reflect the ability to quickly and effectively change production capacities, as well as to set up economically effective production of innovative products that meet the needs of the market. Thus, the technical and technological component characterizes the conformity of the material, technical and technological base, the availability of reserves or the possibility of their quick acquisition, the flexibility of equipment and technologies, the efficiency of the work of design and technological services. Thus, biomass and technical equipment, production technology are only resources for the formation of bioenergy potential, and therefore the resource approach is inappropriate.,

According to the systemic approach, the "bioenergy potential" of any economic system can be considered as a cumulative opportunity for the production of material goods using resources that are systemically interconnected. However, this approach does not determine the purpose of using the potential, so it is somewhat limited.

The effective approach to the interpretation of the "bioenergy potential" category is the most objective. According to this approach, not only available and potential resources are taken into account, but also the possibility of their use for the relevant tasks. Thus, the concept of "bioenergy potential" is directly related to production, as a result of which biomass resources are transformed into a new quality. Thus, the bioenergy potential is a reflection of the possible achievement of effective final results in the most expedient way of using existing resources.

Bioenergy potential is proposed to be considered as a production system, which is the use of available and strategically possible biomass, which is expressed in the potential production capacity of energy sources of a certain composition, technical compliance and quality in the required volume.

The resource component of bioenergy potential is the basis for its formation. This component contains elements of various functional purposes - biomass resources, technical and technological resources.

The importance of each of the resources is manifested in the production process and is characterized by the influence of each on the result. The value of the importance of each component is variable and is determined by the degree of involvement of new elements in the production process.

The second component is the resulting component, which reflects the final result of the formation of bioenergy potential.

Summarizing the above, it should be noted that when interpreting the concept of "bioenergy potential", it is advisable to adhere to an effective approach, which assumes not only the actual availability and possibility of using resources in the future, but also the possibility of using them to achieve certain goals.

On the basis of the conducted research, the content of the category "bioenergy potential" is revealed and it is proposed to consider it as a production system, which represents the use of available and strategically possible biomass, which is expressed in the potential capacity to produce energy sources of a certain composition, technical compliance and quality in the required volume. This definition of "bioenergy potential" takes into account two aspects: on the one hand, "bioenergy potential" is the availability of resources, on the other hand, it is a category that characterizes the ability to produce certain material goods. Thus, a variant of the structuring of the bioenergy potential with formative components - resource-based and productive - is proposed.

Legislation and regulatory framework for the development of bioenergy In the world of production and use of biofuels, there is a significant level of growth, which is influenced not only by the development of the industry, but also by the number of countries that have begun to actively engage in this industry. The investment attractiveness of biofuel production is stimulated by the following factors: state programs, the development of biofuel production technologies, as well as the increase in the price of petroleum products. As a result, new markets for their products are created for agricultural producers, at the same time there is a partial decrease in dependence on imported fuel and, accordingly, its prices, and the negative impact on the environmental situation is reduced.

Issues in the field of bioenergy in the context of regulatory, environmental, social and economic aspects are dealt with by a number of Ukrainian and foreign researchers, in particular: F. Isermeyer, H. Geletukha, H. Kaletnik, M. Kalinchyk, Y. Tsedis, O. Shpychak and others . At the same time, to date, the question of the further development of alternative energy, including bioenergy, remains open, this is primarily due to an imperfect regulatory and legal mechanism, social and economic instability, which to some extent limits the perception of this resource as a guaranteed supplier energy resources to the consumer.

The basis for the development and distribution of biofuels is the legislative framework in this field. World practice points to various ways of stimulating the production of energy from renewable sources, including bioenergy. Pioneers in the production of biofuel are the USA, Brazil and member states of the European Union.

In 2005, the American government adopted the Energy Policy Act, which aims to stimulate the development of the biofuel market. 10 of this Act includes: Standard of renewable energy sources, according to which the task of producing ethanol at the level of 28 billion liters by 2020 is set; loans are guaranteed; tax rates on biofuels are reduced and their production, research and development in the field of bioenergy are effectively stimulated; projects of bioprocessing enterprises are demonstrated; the use and distribution of E 85 ethanol is stimulated.

According to the Farm Bill, approved by the US Congress in 2008, it is provided for the reduction of the tax credit for the production of ethanol from corn from 0.51 to 0.45 $ per 1 gallon and the introduction of the tax credit for ethanol obtained from cellulose in the amount of 0 .1$ per 1 gallon.

It should be noted that the American government in regulatory documentation gives greater preference to the production of bioethanol, compared to biodiesel fuel.

The introduction of tax incentives plus mandatory blending, as well as the application of other incentives, have helped attract capital to bioethanol production. The cultivation of sugar cane was stimulated by the provision of subsidies, which resulted in the construction of new enterprises for the production of bioethanol, the stimulation of the domestic consumer market and the formation of a logistics infrastructure for the supply of bioethanol.

Biofuel policy in the EU is based on two Directives 2003/30/EC and 2003/96/EC adopted on May 8, 2003. These directives provide for increasing the share of biofuel in general use from 2% in 2005 to 5.75% in 2010 of the biofuel content in traditional types of fuel.

However, it should be noted that the EU has not fulfilled its obligations to date. European Union Directive 98/70/EC, as amended by Directive 2003/17/EC, refers primarily to compliance with environmental standards in biofuel production. It provides for a limit of 5% on the addition of bioethanol to mineral fuels, based on environmental considerations. The EU Commission has proposed amendments that include an increase in the share of bioethanol to 10%. In the Green Book of the European Commission entitled "Towards a European Strategy for Reliable Energy Saving" published in 2001, the problem of 12 high indicators of energy dependence of the European Union is defined. In May 2007, in Brussels, according to the decision of the round table of EU member states, it was decided that the share of renewable energy by 2020 should be 20% of the total amount of energy resources used, and 10% belongs to biofuels. An analysis of the main principles of the EU Directive 2009/28/EC regarding the promotion of the use of renewable energy, which was adopted in 2009, shows that the policy of the European Union regarding the spread of the use of biofuels includes the following main factors: safe supplies of raw materials both within the Union and to the states " of the third world"; reduction of the amount of emissions into the atmosphere, which is measured according to the methodology that takes into account changes in the use of land resources; development of rural areas; social stability.

In our opinion, this EU Directive allows for a long-term strategy for the development of renewable energy, and for the production of biofuel, it contributes to the predictability of the actions of the EU member states, which has a significant impact on the decision-making process on further investment in this area.

The biofuel industry of our country is in its nascent stage. In 2000, the Law No. 1391-XIV "On Alternative Types of Liquid and Gaseous Fuels" was adopted. This Law defines the legal, economic, ecological, social and organizational principles for the production and use of alternative types of fuel based on the use of non-traditional sources and types of energy raw materials, aimed at forming the necessary prerequisites for the development of the production and use of these types of fuel. However, it should be noted that it has a more declarative nature. In order to ensure the stability of the development of production and use of bioethanol in the middle of the country, as well as for the purpose of economic stimulation of oil refineries for the production of mixed petroleum products, the Law of Ukraine "On Amendments to 13 Certain Laws of Ukraine on Stimulating the Production of Motor Blended Gasolines" was adopted.

This law provides for the establishment of a reduced rate of excise duties - 30 euros per 1 ton of blended gasoline, provided that the share of bioethanol in it will be more than 2%. For the implementation of this Law, the Ministry of Fuel and Energy has identified oil refineries that have the ability to produce mixed gasoline with bioethanol and plants that produce this bioethanol. Although the volume of bioethanol production has not changed much in recent times, there has been an increase in interest from both the state and producers. In accordance with the Law of Ukraine "On Excise Duty and Import Duty Rates on Certain Goods (Products)" with amendments and additions introduced in accordance with the Law "On Amendments to the Laws of Ukraine" and "On Excise Duty and Import Duty Rates on Certain Goods (Products))" from July 1, 2009, the excise tax for 1,000 kg of gasoline mixture containing at least 5% ethyl tert-butyl ether or high-octane oxygen-containing admixture, or their mixture, is 110 euros. The excise tax on the production of oxygen-containing high-octane gasoline additives is 0 euros, while their production with subsequent mandatory mixing with gasoline is possible at state distilleries, the determination of which is the prerogative of the Cabinet of Ministers of Ukraine.

In May 2009, the Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding Promotion of the Production and Use of Biological Fuels" was adopted. The purpose of this law is to stimulate the production and use of biofuel, the formation of the Ukrainian fuel market due to the use of biomass, as one of the types of renewable sources of energy raw materials for the production of biofuel. In accordance with this law, the following basic rules are provided: the list of factories that produce motor blended gasoline with the addition of bioethanol, ETBE and bioethanol-based additives is established by the Cabinet of Ministers of Ukraine; production of 14 bioethanol can be carried out at enterprises of all forms of ownership if the necessary license is available; providing bioethanol producers with tax invoices in the amount equal to the excise duty; until January 1, 2017, a zero rate of excise duties was established on the portion of fuel that is a biocomponent in motor mixed types of fuel; temporarily, until January 1, 2017, the delivery of equipment, machinery, and equipment is exempt from taxation; since January 1, 2010, the income of enterprises received from the simultaneous production of thermal and electric energy and/or production of thermal energy using biological types of fuel was exempted from taxation; profit of manufacturers of equipment, machinery, and equipment received from sales on the territory of Ukraine; funds received in connection with the receipt of tax benefits are sent by the taxpayer to reduce the price of products; in the period until January 1, 2019, in order to stimulate investment activities, the purpose of which is the renewal of fixed assets, the use of a bonus type of depreciation of new fixed production assets is allowed, which consists in attributing the share of costs that go to their purchase (construction) to the gross costs that remain after using bonus depreciation; by 2020, increasing the share of the use of alternative types of fuel to 20 percent of the total volume of fuel consumed in Ukraine; biofuel intended for further sale in the form of commercial products is subject to mandatory certification in accordance with current legislation; maintaining state registration of producers of biogas and liquid biofuels, etc.

The largest specific weight in the total volume of biomass is: cereal straw - 5.6 million tons. p. / year, energy crops - 5.1 and liquid biofuel - 2.2. In the Energy Strategy of Ukraine until 2030 adopted in 2006, the achievable annual energy potential of non-traditional and renewable energy sources (NRE) of our country, in terms of conventional fuels, is 79 million tons. p., in particular economically efficient - 57.7 million tons. p.

An important impetus to the use of biomass in the production of electricity and thermal energy in Ukraine is the adoption of the following normative documents: the Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Establishment of a "Green" Tariff", the Law of Ukraine "On Amendments to the Law of Ukraine "On Electricity" on stimulating the use of alternative energy sources". Thus, the first law stipulates the obligation for the wholesale electricity market to buy electricity in accordance with the "green" tariff from electricity producers who use alternative sources of energy in their activities (except blast furnace and coke gases, and with the use of hydropower - obtained only at small hydroelectric power stations), and not sold at the contractual price directly to consumers or energy suppliers who conduct their economic activity in the supply of electricity at regulated tariffs. The new edition of the Law of Ukraine "On Amendments to the Law of Ukraine "On Electric Power" on Stimulating the Use of Alternative Energy Sources" is broader and has clarifications on the essence of the application of "green" tariffs. The procedure for stimulating energy production using alternative energy sources and 16 is used under the condition that, starting from 2012, the specific weight of materials, raw materials, fixed assets, works and services of national origin in the total cost of creating a corresponding facility for the production of electric energy that produces electricity using alternative energy sources, is more than 30%, and since 2014 - 50%.

Another condition for the use of the noted procedure for stimulating the production of electrical energy from the sun is the use, starting in 2011, of solar converters by electric power facilities, the specific weight of raw materials and materials of Ukrainian origin in the production cost of which is more than 30%. These laws provide that suppliers of electric energy, which are engaged in the transmission of electricity using their own power grids, cannot deny access to these networks to enterprises that receive energy using alternative energy sources. Therefore, in the future, we can expect an intensification of investment activities, in particular, in the field of construction of wind power plants, obtaining electrical energy from biomass, etc.

In the classical approach, efficiency is considered as the ability to bring an effect, the effectiveness of a process, project, etc., which are defined as the ratio of the effect, result to the costs that ensured this result.

In our opinion, the ecological and economic efficiency of biofuel production is a complex of material (economic) and non-material (ecological, natural-climatic, social) effects obtained as a result of using biofuel as an energy source.

When evaluating the ecological and economic efficiency of biofuel production from agrobiomass, it is necessary to take into account a complex of components, including economic, ecological, social, energy, political and nature-climatic ones.

Ecologically unbalanced management of economic activity, imperfection of the legislative environmental protection system, ignoring by some principles of the ecological economy leads to such problems as the reduction of reserves of renewable and non-renewable resources, the deterioration of the global state of the environment, and the deterioration of the health of the population. Using one of the methods of the digital economy - a systemic approach, it is possible to improve the state and level of efficiency of ecological and economic systems by applying the principles of synergy, as a result of which a positive synergistic effect should appear.

Today, in the conditions of the energy crisis, real conditions have been created for the development of renewable energy sources and biofuel production. At the same time, the state should be the main driving force in the development of the biofuel market. The prerequisite for biofuel production in Ukraine on a commercial scale should be a strong domestic market, guaranteed by the mandatory use of mixed fuel based on traditional and biological, as well as the implementation of state norms of product quality, which must coincide with EU norms. These measures, with the growing demand for biofuels in Europe, will contribute to the growth of the level of involved domestic and foreign investments and technologies in the production and use of biofuels.

Before considering the prospects of attracting investments in projects related to the use of agrobiomass for the production of biofuel, it is necessary to consider the main prerequisites that have a significant impact on the decision-making of potential investors.

Thus, as a result of the conducted analysis, it was established that in order to calculate the ecological and economic efficiency of obtaining biofuel from agrobiomass, it is necessary to take into account economic, ecological, social, energy, political and nature-climatic components. This list includes the entire complex of effects - from the efficient production of agrobiomass and the organization of biofuel production, to the use of the final product. The proposed methodology for assessing the ecological and economic efficiency of using agrobiomass for biofuel production is comprehensive and takes into account all multidirectional effects.

The world is in the midst of its first global energy crisis. Every energy crisis has echoes of the past. High energy prices have created strong economic incentives and these incentives are reinforced by economic and energy security considerations.

Therefore, the development and production of bioenergetic fuels is becoming more and more relevant every year.

Emissions of sulfur dioxide, carbon dioxide and nitrogen dioxide from the burning of fossil fuels are the main causes of atmospheric pollution. At current rates of consumption, known oil reserves are expected to be exhausted in less than 50 years. In developed countries, there is a growing tendency to use modern technologies and effective transformation of bioenergy from a number of biofuel sources, which are becoming more economically efficient compared to fossil fuels.

The production of biogas from organic waste for farms of various sizes and areas of specialization is economically feasible, it makes it possible to meet the energy needs of the farm and to get a profit from the processing of 1 thousand tons of pig and cattle dung into biogas in the amount of UAH 119-136.8 thousand.

The use of vegetable raw materials and manure in different ratios can be an effective factor in increasing the yield of biogas and increasing the useful effect of biogas power plants.

The raw material consisting of 75% of the green mass of corn and 25% of pig and cattle manure, respectively, is the most efficient in the production of biogas.

At the same time, the production of biogas at alcohol and sugar factories in the region will be able to provide the following ecological and economic effect for the economy:

1. to increase the energy independence of the relevant industries of the Vinnytsia region;

2. to reduce energy costs of alcohol and sugar plants;

3. to improve the ecological condition of the region's water resources;

4. to reduce the amount of greenhouse gas emissions;

to provide the livestock industry with protein feed, and agriculture with high-quality biofertilizers

One of the promising ways of stimulating the improvement of reliability at the stage of design and production of the equipment of technological lines of biogas plants is the inclusion in the cost of the equipment of maintenance and repair costs for the maximum possible service life. In this case, developers are interested in obtaining accurate estimates of the potential reliability and durability of equipment, and manufacturers in improving the quality of their products. An important factor in increasing the reliability of the equipment is the consideration when designing the specific conditions in which the technological line will work.

It is necessary to take into account the following operational factors affecting the reliability of the equipment of technological lines of biogas plants:

1. Working conditions. It is necessary to take into account the presence of an aggressive chemical environment, strong vibrations, shocks, the presence of radiation, electromagnetic influences, standards and quality of electrical power, water supply, sewage, ventilation, chemical reagents, etc.

2. Climatic conditions (temperature, humidity, air pollution by chemical substances, etc.).

3. Biological factors (insects, rodents, mold, fungi, etc.). Structural and functional methods of increasing reliability include the use of such schemes for the construction of technological processes, in which the failure of individual elements does not disrupt the functioning of the entire system.

Biomass is a non-fossil biologically renewable substance of organic origin, capable of biological decomposition, in the form of products, waste and residues of forestry and agriculture (plant and animal husbandry), fisheries and technologically related industries, as well as a component of industrial or household waste , capable of biological decomposition. Biomass is considered a renewable source of energy because the energy it contains is produced in the process of photosynthesis, when plants convert the radiant energy of the sun into carbohydrates.

Growing plants specifically for conversion into biomass is essentially a form of solar energy conservation. When biomass is burned, carbohydrates release heat, carbon dioxide (CO2, the so-called "greenhouse" gas) and water. Carbon dioxide is returned to the environment and participates in the carbon cycle, contributing to the growth of other plants and replenishment of burned biomass. Thus, the burning of biomass with the correct organization of the process does not lead to additional pollution of the environment with carbon dioxide. Water returns to the natural hydro cycle - the cycle of water in nature. Heat from burning biomass can be used to generate electricity, as well as for other energy needs of mankind. At this stage of technology development, there are other options for using biogas besides burning and obtaining heat, such as: generators for obtaining electrical energy and cogenerators for obtaining thermal and electrical energy.

In addition, at this difficult stage for our country, one of the promising ways of using biogas is to purify it into biomethane, to receive guests, when it becomes an analogue of natural gas, and in some cases even better, and pumping it into the gas distribution network.

Taking into account the availability of raw materials, we will indicate the segments of the agricultural industry where it is appropriate to consider the implementation of projects for the construction of biogas plants:

- grain cultivation (grass, silage, cultivation of special energy plants, straw after preparation);
- animal husbandry (manure, droppings, waste from slaughterhouses);
- solid household waste processing;
- production of biodiesel and rapeseed (glycerin);
- potato production (cleaning, rotting);
- production of starch and molasses (pulp, syrup);
- production of dairy products (salted and sweet whey);
- production of beer and other alcohol (grain and molasses, beer grist).

Biomass and biofuels can be used as an alternative to fossil fuels in the production of heat, electricity and transport. This has several advantages:

1 use of renewable energy sources. The biological materials used in biomass are renewable resources that can be grown or regenerated;

2) reduction of carbon emissions. The use of bioenergy can reduce dependence on the use of coal and oil, contributing to the reduction of greenhouse gas emissions;

3) development of agriculture. The use of biomass can contribute to the development of agriculture, especially in countries with a developed agricultural

sector.

However, there are also certain disadvantages:

1) costs and difficulties with the collection and processing of biomass, especially when transporting over long distances;

2) competition with food industry products for the use of land and other resources;

3) the production of some types of biofuel can lead to a decrease in biodiversity and pollution of water resources, if appropriate measures for waste management and environmental protection are not taken.

Therefore, the rate of development of bioenergy in Ukraine is significantly behind the European ones. The development of bioenergy in Ukraine, along with solving the issues of economic security and economic independence, will contribute to increasing environmental security and reducing the negative impact on the surrounding natural environment.

According to experts, Ukrainian distilleries, which have their own anaerobic raw material base, have good prospects for biogas production. Based on the capacity of existing Ukrainian distilleries, on average, a distillery can save up to 165 million cubic meters of energy due to biogas. m of natural gas per year. Moreover, on December 3, 2019, a law was adopted in Ukraine, which will abolish the state monopoly on the production of alcohol from July 1, 2020. The law provides an opportunity for business entities, regardless of the form of ownership, to produce alcohol if they have the appropriate license, and also provides for full liberalization of alcohol exports from Ukraine

The assessment of the energy potential of biomethane production in Ukraine is based on an analysis for the year 2022 of the level of production of main crops by agricultural enterprises, products of the food processing industry, the available livestock of cattle, livestock, pigs and poultry at livestock enterprises, as well as the volume of solid household waste and sewage of water in the communal economy.

There are two basic concepts of biomethane production projects from biogas. The first concept envisages the construction of a new complex for the production of biomethane "from scratch", including a biogas plant and a biogas enrichment plant. The second concept involves the full or partial repurposing of existing biogas plants from the production of electricity and/or thermal energy to the production of biomethane, with the completion of a biogas enrichment plant and, if necessary, the reconstruction of the biogas plant.

In order to evaluate the expediency of switching to biomethane production, existing operators of biogas plants need to find answers to at least the following questions:

- what measures and funds are necessary to extend the service life of the biogas plant?

- is there a possibility to increase the capacity of biogas production? if so, what additional investment is required in additional capacity?

– does the existing biogas desulphurization solution meet the requirements of the biogas enrichment system for biomethane? if not, what additional investment is required in a new desulfurization unit?

– is there enough territory to place a biogas enrichment station and additional biogas production facilities? Space limitations can affect the choice of biogas enrichment technology.

- what part of the equipment for the production of electricity (CHP) will remain in operation to provide electricity for both the biogas plant and the biogas enrichment plant?

– what are the technical conditions for connection to the natural gas network on site (pressure, minimum consumption, etc.)?

In Ukraine, there is a need to improve the efficiency of waste management of agricultural enterprises in accordance with European and global trends. A promising direction is the use of agricultural waste for energy purposes - the production of biofuel. Obtaining biogas from agricultural waste makes it possible to partially solve a number of problems facing the agricultural sector of the country:

- economic - increasing the competitiveness of agricultural products due to the reduction of energy costs during its production;

- energy - own production of fuel, ensuring the energy independence of agricultural enterprises;

- agrochemical - obtaining environmentally friendly fertilizers;

- ecological - disposal of organic waste that harms the environment;

- financial - reducing costs for the disposal of organic waste and the purchase of traditional energy carriers;

- social - creation of new jobs.

Ukraine considers nuclear energy as one of the most cost-effective low-carbon energy sources. Further development of the nuclear power sector for the period up to 2035 is predicted based on the fact that the share of nuclear generation in the total amount of electricity production will grow.

Revolutionary technological innovations are expected in the field of transport. Ahead - in the coming decades - we expect a progressive abandonment of internal combustion engines of hydrocarbons and the replacement of a significant part of such vehicles with rolling stock that will use emission-free electric motors and ecologically clean hydrogen engines.

The memorandum of understanding between Ukraine and the EU on cooperation in the energy sector dated November 24, 2016 establishes the strategic role of Ukraine as a transit country, however, in general, the EU strategy is no longer focused on the potential of Ukraine as the most important energy communication link in the East, since the interests of individual, more influential of member states prevail over jointly defined priorities.

The extension of European energy standards to Ukrainian legislation is able to significantly increase Ukraine's resistance to attempts to politicize interstate relations in the field of energy, and joining the European market is to liberalize and demonopolize domestic energy markets, make them more transparent and competitive. The transformation and integration of markets is only possible if one of the main players is the consumer, as required by Goal 7 of the 2015 United Nations Agenda for Sustainable Development 2030 Agenda for Sustainable Development.

The strategic task is to bring the state to the level of maximum energy independence. At the same time, by 2025, the main focus should be energy conservation, maintenance of the achieved volumes of hydrocarbon production and maximum diversification of the supply of primary energy resources.

For the period until 2035 - successful implementation of projects for the development of natural gas deposits, including from unconventional sources. As a result of the system transformation, the energy infrastructure should become a flexible tool of the energy security system of Ukraine, a basis

Without a threat to food security and the export potential of the state, about 10 million hectares of agricultural land can be used for growing energy crops with their subsequent processing into biofuels, in order to ensure the energy independence of the agro-industrial complex and Ukraine. That is, the potential opportunities of our country for the cultivation of energy bio-raw materials and the production of biofuels are quite high.

Special attention should be paid to the development of biofuel production in conditions of rising energy prices. However, it should be noted that today the potential of agricultural crop waste in the form of straw and waste from oil refineries is used to a small extent, which can significantly increase the production of solid biofuel in the short term.

In the conditions of refusal to import energy carriers from the Russian Federation, the supply routes from the EU countries are being adjusted today.

However, the purchase of natural gas and gas oils in conditions of rising prices on the EU market is quite expensive, so it is necessary to develop directions for improving the cultivation and production of agrobiomass for biofuel, including biogas and biodiesel.

Biomass belongs to renewable energy sources that are powerful in terms of volume, diverse in purpose and use of technologies. It should be noted that types of biomass differ from each other in terms of both chemical and physical characteristics, have a wide range of applications, which is determined by the variety of types of fuel obtained from it. The source of biomass can be agricultural crops that have a high calorific value, perennial plants, as well as agricultural and forestry waste.

Biomass energy can be used to produce electricity, thermal energy, liquid fuels (ethanol, biodiesel), synthetic and biological gas. For each type of bioenergy resources, separate technologies are used for energy production. Therefore, taking into account the above, it should be noted that biomass without technical processing is only a resource, because the energy potential is estimated through the indicators of electricity and gas and heat supply. According to the alternative production technology, thermal and electrical energy from biomass is realized in two stages: the first stage is the conversion of biomass into new fuel and the second stage is the burning of new fuel in modern power plants.

Technical and technological resources, due to which biomass is transformed into bioenergy potential, reflect the ability to quickly and effectively change production capacities, as well as to set up economically effective production of innovative products that meet the needs of the market. Thus, the technical and technological component characterizes the conformity of the material, technical and technological base, the availability of reserves or the possibility of their quick acquisition, the flexibility of equipment and technologies, the efficiency of the work of design and technological services. Thus, biomass and technical equipment, production technology are only resources for the formation of bioenergy potential, and therefore the resource approach is inappropriate.

According to the systemic approach, the "bioenergy potential" of any economic system can be considered as a cumulative opportunity for the production of material goods using resources that are systemically interconnected. However, this approach does not determine the purpose of using the potential, so it is somewhat limited.

The effective approach to the interpretation of the "bioenergy potential" category is the most objective. According to this approach, not only available and potential resources are taken into account, but also the possibility of their use for the relevant tasks. Thus, the concept of "bioenergy potential" is directly related to production, as a result of which biomass resources are transformed into a new quality. Thus, the bioenergy potential is a reflection of the possible achievement of effective final results in the most expedient way of using existing resources. Bioenergy potential is proposed to be considered as a production system, which is the use of available and strategically possible biomass, which is expressed in the potential production capacity of energy sources of a certain composition, technical compliance and quality in the required volume.

In the conditions of refusal to import energy carriers from the Russian Federation, the supply routes from the EU countries are being adjusted today. Currently, on the basis of the research and production capacities of NNVK "All-Ukrainian Scientific and Educational Consortium" of the research and production laboratory focused on improving the cultivation of agrobiomass and the provision of services for the processing of energy crops into biodiesel and the creation of prototypes of installations for the production of biogas by private peasant farms. The existing laboratory is currently undergoing a modernization process, including in the production cycle equipment for processing energy crops into oil and cakes, improving technologies for growing the relevant crops and developing prototypes of small biogas plants.

Therefore, the growing competition in the world energy markets and the rapid scientific and technical progress in the development of renewable energy sources and alternative types of fuel expand the opportunities for Ukraine to choose sources and ways of supplying primary energy resources, optimize the energy mix and, in the future, reduce greenhouse gas emissions.

Considering the limited amount of natural resources and the tendency to increase the number of the population, the existing linear model of the economy based on the principle of "take-make-use-dispose" needs to be reconsidered. The idea underlying the circular economy model, according to which today's goods should become tomorrow's resources, is becoming more and more relevant. The closed cycle model, among other things, includes the need to minimize waste as much as possible or rationally process it. Under these conditions, the agricultural industry should, first of all, ensure food security, activate the production of biomass as a renewable energy source, since bioresources and biomass make up the highest share in agriculture. A significant part of secondary resources is used inefficiently, which leads to environmental and economic losses. Therefore, the issue of the transition of economic entities in the agrarian sphere to waste-free production due to the processing of waste and by-products is becoming more and more urgent. It is the circular economy that offers alternative solutions that could use innovation, promote economic growth and, most importantly, produce useful resources for society and the environment.

The concept of circular economy is relatively new in scientific usage. In the scientific community, there is currently no single or at least agreed approach to understanding this concept. One of the important aspects is that the very concept of the circular economy originated within the scientific research of legislators, politicians and environmentalists, and not in the academic community, as is usually the case. The main component concepts are the principles of 3R: reduction (Reduce), reuse (Reuse) and recycling (Recycle), a fourth principle is also proposed - corporate social responsibility (Responsibility), which is mandatory during the formation of global circular chains of creation of added value. Bioenergetics as an irreversible alternative to the use of resources occupies a special place in research on the prospects of a circular economy. About 80% of all energy comes from fossil fuels and only 20% from renewable energy sources, among which bioenergy occupies an important place. In developing countries, bioenergy is used for cooking and heating. About 79% of the world's total conversion of biomass into thermal energy takes place in Asia and Africa. Biomass is a core element of the European Bioeconomy Strategy, adopted in 2012 and re-declared in 2018. Agriculture is the largest biomass supply sector in the European Union, accounting for 65%. This is due to the fact that the result of agricultural activity is a significant amount of by-products and waste. However, waste is only partially processed into value-added products, while the bulk is not used, causing environmental problems and affecting the global sustainability of agriculture. The main reason is that it may not be economically feasible due to low market prices of products, low quality and seasonality, high transport costs and water content. Researchers note a number of external factors that affect the bioenergy potential of agricultural waste, including weather conditions, location and existing ecosystem, and properties of raw materials. Bioenergy production is a major global initiative (and a real alternative) to increase energy security while mitigating climate change. However, the development of bioenergy together with the growing demand for food may lead to food and fuel competition for bioproductive land. Therefore, many scientists do not support the rapid development of the bioenergy direction, taking into account the potential problems that may arise as a result of the limited use of land resources. Among the arguments - intensifying competition for raw materials, which are necessary for both food production and fuel production; the need for significant "start-up" costs for the transition to bio-based technologies; the lack of necessary infrastructure and logistical problems leading to high costs of transportation, storage of raw materials, etc., and thus increasing the cost of the initial "bioproduct", thereby making it uncompetitive compared to traditional analogues.

In general, domestic scientists note that the use of bioenergy resources has not become widespread. This can be explained by the lack of practice of centralized harvesting of biomass; the lack of technological support for the production of fuel cells due to the specificity of biomass; lack of specialized equipment for consumers to burn the appropriate type of fuel; the absence of an agrofuel exchange; lack of developed logistics schemes; and therefore - the level of development of the industry in general. The long-term impact of bioenergy, which provides a significant share of the world's energy demand, requires a deeper analysis in view of environmental factors and constraints. The development of effective strategic solutions and guidelines is an important task for the industry, which determines the relevance of the research.

To overcome major global challenges such as pollution, climate change, energy and food security, inequality and poverty, the sustainable development of the bioenergy sector must take into account environmental and social impacts, as well as economic feasibility. The modern bioenergy industry is aimed at the valorization of biomass (in particular, of agricultural origin), which is the main mechanism for implementing the principles of circular economy in the agricultural sector. When developing a strategy, it is important to predict the optimal ways of transporting agricultural waste. The work studies the technical potential and geographical distribution of agricultural residues and by-products in the European Union. A geographic information system (GIS) is a powerful tool that analyzes large volumes of spatial data and is widely used to display cartographic information about biomass resources, logistics networks, land use, and potential industrial sites. The obtained information can be used when planning new logistics centers for waste processing, searching for the most appropriate location. Most of the world's research in the field of bioenergy uses the term "biorefining" (English: biorefining). According to the definition of the International Energy Agency (IEA), biorefining is the permanent processing of biomass into commercial products based on biological raw materials and bioenergy (fuel, energy, heat). Here, the sustainability of recycling is an important point. If biorefineries use unsustainable methods, long-term success is unlikely. Therefore, their activities should be outlined and modeled from the point of view of ecological, economic and social integration and expediency. As is well known, economic growth usually leads to increased use of resources, which can cause a number of environmental and social problems. It is proposed to look for solutions in eliminating the negative relationship between economic and environmental mechanisms, developing new ideas about business models and strategies within the circular economy. The sustainable development of agriculture in the conditions of a circular economy requires a rethinking of clear guidelines in the direction of economic growth, since potential economic indicators can be devalued by losses from inefficient use of natural resources, damage to the environment, land degradation, etc. The development of bioenergy must be supported by state support, but at the same time, economic competition with other energy sources is also important.

We offer the following strategic goals for the use of bioenergy potential:

- environmental: ensuring sustainability of the agar sector, preservation of biodiversity;

- economic and political: increasing the level of energy security of the state, increasing the profitability of production;

- social: improving the quality of life of the population, developing the infrastructure of rural areas;

- technological: introduction of innovative technologies for production of agricultural products and processing of its waste.

On the basis of the above goals, we form strategic guidelines for the development of sustainable use of biomass in territorial communities:

- use biomass that is obtained only taking into account the principle of sustainability. It is important to adhere to the strategy of responsible land use, minimize soil depletion, and monitor the correct distribution of agricultural crops. The transition from traditional biofuels should involve minimal changes in land use. Effective crops should be allocated land that suits them as best as possible, in order to obtain the maximum amount of both feed, food and waste. Also important is the issue of prioritizing food over fuel, which emerged as a result of the rise in global prices for basic agricultural commodities in recent years, along with the rapid growth in the use of biofuels at the beginning of the 21st century.

From the principle of sustainability follows the question of respecting biodiversity. As you know, agricultural production in general has a significant impact on nature and the environment. This impact can also be negative, as for example, when lands with significant biodiversity are used for agricultural purposes. At the same time, it is advisable to take into account the criteria given in the EU Directive 2009/28/EC. Among the most important for bioenergetics, it is worth noting the criterion regarding the preservation of soil fertility (for this, an analysis of the mass balance of substances in the soil due to activity is carried out); the criterion for banning the use of areas critical for the preservation of biodiversity for the cultivation of raw materials intended for the production of biofuels.

Promote the use of research, development and innovation at various stages. To optimize financial returns, cooperation with interested parties is necessary at all stages of the implementation of the model. Establishing cooperation and partnership with industry and consumers to improve access to the market for products of biological origin is especially relevant.

The development of the domestic geographic information system, which has already been discussed, is a primary task for scientists. For bioenergy entrepreneurs, it is important to have close links with research institutes, as well as manufacturers and marketers, to ensure the development of highly specialized products, a continuous flow of raw materials and the sale of end products. The reasons for the failure of many bioenergy projects are the lack of high-quality and inexpensive equipment for the use and processing of biomass. Combustion of biomass in inappropriate boilers that pollute the environment does not meet modern requirements of sustainable development. It is necessary to stimulate innovation using various instruments, including financial ones. The main strategic orientation is state support for research, namely the allocation of funds for scientific and technical developments and research in the field of bioenergy.

Adhere to the principles of optimal use of biological resources. The transformation of low-value agricultural waste and by-products into marketable end products requires specific value creation strategies, such as the biomass value pyramid.

At the lowest level are products obtained by burning biomass and converting it into heat and electricity. Higher value products can be extracted from biomass by treatment with fungal enzymes. The cascading use of biomass plays an important role in the development of the circular economy.

Transformation of business models of players in the bioenergy market. The way of finding and supplying raw materials, the type of partnership, cooperation and relations at different stages of the bioenergy chain should be reconsidered. Collection of waste and by-products is a particular challenge as it involves significant costs related to logistics, seasonality and variability. Therefore, it is important to create long-term partnerships with local farmers and agribusinesses. In circular business models, the typical customer-supplier relationship is transformed. Responsibilities are divided, for example, the customer is also responsible for the quality of its supplier's products, since its products are partly used by the supplier (circular economy concept). In this context, an important role is also played by the local government as a full participant in the bioenergy market, as well as its strategic orientations.

Therefore, the strategic task is to develop a mechanism for additional payments from the local budget for the use of biomass waste products of plant and animal husbandry for energy needs. For the successful implementation of the circular business model in the agricultural industry, it is necessary to take into account the interests of all market participants, based on the principle of sustainable development. At the stage of transformation from a linear to a circular economy, agriculture needs changes in existing business models in order to increase the innovative component, improve logistics processes, and develop a strategy for realizing the existing bioenergy potential of rural areas in general. At the same time, it should be understood that the benefits expected from the bioenergy sector are possible only in the long term.

During the war with the russian federation, the problem of Ukraine's energy independence became more acute, therefore the production of biofuels is extremely important.

Bioenergy is a form of renewable energy that derives from organic material. In this context organic matter refers to biomass, e.g. wood, straw, manure, agricultural products and by-products as well as the organic fraction of municipal solid waste, catering waste and residues from the food processing industry. The processes to convert organic matter into energy can be physical, chemical, thermal, biological or a combination of those.

The main obstacles to the development of bioenergy, in addition to the war, are the lack of approved long-term goals, the uncertain state position on the energy use of agricultural residues.

At the global level, by 2050, biomass can provide the production of 3,000 TWh of electricity, which will meet the needs of 7.5% of the world's population, and will also contribute to the reduction of CO_2 emissions by up to 1.3 billion tons per year. In turn, Sweden and Austria provide 15% of the need for primary energy sources due to biomass, and the USA - 4%. The calorific value of dry biomass is about 14 MJ/kg [1, p. 11].

The sector of energy production from biomass is regulated in Ukraine by a significant amount of legislation, but the main «framework» laws that determine its legal basis are the Law of Ukraine «On Alternative Fuels» [2] and the Law of Ukraine «On Alternative Energy Sources» [3].

They defined the main terms used by representatives of the sector, in particular, the term «biomass», «biofuel», «biogas», «biomethane» and others. In general, regulation of the bioenergy sector can be divided into several subsectors.

1. Production of thermal energy from biomass.

The procedure for the production of heat energy from biomass, in particular the tariffs for heat energy from alternative sources, are regulated by the Law of Ukraine «On Heat Supply» [4]. Article 20 of the said law provides for the so-called «0.9» principle, which means that the tariff for thermal energy produced from alternative energy sources is set at the level of 90% of the tariff for thermal energy produced using natural gas, for the needs of the corresponding category of consumers (population and budgetary organizations). If the producer of thermal energy does not have a set tariff for thermal energy from natural gas, 90% is deducted from the weighted average tariff for thermal energy produced using natural gas for the needs of the corresponding category of consumers. The specified weighted average tariff by region is approved quarterly by the State Energy Efficiency Agency in accordance with the procedure determined by the Resolution of the Cabinet of Ministers of Ukraine «On approval of the Procedure for calculating weighted average tariffs for thermal energy produced using natural gas for the needs of the population, institutions and organizations financed from the state or local budget, its transportation and supply» dated September 6, 2017 № 679 [5]. A similar tariff setting procedure is provided for tariffs for the production, transportation and supply of thermal energy.

Today, unfortunately, the often established tariffs for heat energy from alternative energy sources are not enough to ensure the attractiveness of projects for the production of heat energy from biomass, in this connection the issue of amending Article 20 of the Law of Ukraine «On Heat Supply» is being considered [4] so that producers can calculate the tariff based on economically justified costs. Another reason for the lack of profitability for replacing natural gas with solid biofuel for the «population» category in individual and centralized heating is the state subsidizing the cost of natural gas for the population by 4-5 times compared to the market value of natural gas.

2. Production of electrical energy from biomass and biogas.

The production of electric energy from biomass and biogas in Ukraine is stimulated with the help of the «green» tariff provided for by the Law of Ukraine «On

Alternative Energy Sources» [3]. The «green» tariff for electricity produced from biomass and biogas is established by the National Commission, which carries out state regulation in the fields of energy and communal services. The «green» tariff is valid until the end of 2029 and is 12.39 euro cents/kWh (without VAT) for electricity obtained from biomass and biogas. The law also provides for the possibility for electric power facilities put into operation from July 1, 2015 to December 31, 2024, to receive a surcharge to the «green» tariff for compliance with a certain level of use of Ukrainian-made equipment. However, today the production of electricity from biomass and biogas is not attractive enough, mainly due to incomplete calculations and indebtedness to electricity producers at the «green» tariff from the Guaranteed Buyer.

The Law of Ukraine «On Alternative Energy Sources» [3] also provides for the holding of auctions for the allocation of support quotas in the production of electricity from alternative sources. Auctions are a way of identifying economic entities that acquire the right to support in the production of electricity from alternative sources. The support itself is carried out by guaranteeing the purchase of the entire amount of electrical energy released by such producers at the auction price, taking into account the allowance for compliance with the level of use of Ukrainian-made equipment. The Cabinet of Ministers of Ukraine, at the request of the Ministry of Energy, establishes the annual support quota and the schedule of auctions for the following year, as well as indicative forecast indicators of the annual support quotas for the next four years, no later than December 1.

Producers of electricity from biomass and biogas can participate in auctions on a voluntary basis. The annual support quota for producers of electricity from biomass and biogas, as well as other types of alternative energy sources, except for solar and wind energy, is at least 10%. The advantage of voluntary participation in auctions for economic entities producing electricity from biomass and biogas is the period of application of support after the end of the auctions. In particular, the term of providing support is 20 years from the day following the date of submission of documents confirming the connection of the object to the electric network and certifying the readiness of the object for operation. However, the auctions have not yet started.

3. Use of biofuel in the transport sector.

Today, the legislation does not provide for adding a mandatory share of biofuel to motor fuels. However, on February 7, 2023, draft law No. 3356-d «On Amendments to Certain Legislative Acts of Ukraine Regarding Mandatory Use of Liquid Biofuel (Biocomponents) in the Transport Sector» was included in the agenda of the Verkhovna Rada of Ukraine for consideration in the second reading [6]. The specified draft law provides for the establishment of a mandatory share of the content of liquid biofuel (biocomponents) in all volumes of automobile gasoline sold from places of fuel production, places of wholesale fuel trade and places of retail fuel trade, with the exception of gasoline with an octane number of 98 and higher and gasoline, supplied for the needs of the Ministry of Defense, the State Reserve and for the creation of minimum reserves of oil and oil products - from May 1, 2022 – at least 5% (by volume), with an absolute error of determination of ±0.5%.

In addition, liquid biofuel (biocomponents), which is taken into account to comply with the normatively determined mandatory share of it in the volume of sales of automobile gasoline in the customs territory of Ukraine, must meet sustainability criteria. According to the definition provided in the draft law, the sustainability criteria are the requirements met by liquid biofuels (biocomponents) and biogas intended for use in the field of transport. These include, in particular, indicators of the reduction of greenhouse gas emissions from the use of the specified types of biofuels and the prohibition of the use of individual land plots for obtaining raw materials necessary for the production of such types of biofuels. Sustainability criteria for biofuels are introduced into the legislation of Ukraine for the purpose of implementing the EU Directives on renewable energy sources.

The underdevelopment of biofuel use in the transport sector is due to several reasons, in particular, high excise tax rates on motor gasoline with a content of at least 5 wt. % of bioethanol and for biodiesel and its mixtures – 100 euros per 1000 liters. In the case of using bioethanol for the production of fuel containing bioethanol, the requirement for a tax bill for the full rate of excise duty required for the transportation of bioethanol is also a deterrent.

According to clause 229.1.1. of the Tax Code of Ukraine [], excise tax is paid at the rate of 0 hryvnias per 1 liter of 100 percent alcohol from bioethanol, which is used by enterprises for the production of motor gasoline blends containing bioethanol, ethyl-tert-butyl ether (ETBE), other additives based on bioethanol , as well as bioethanol, which is used to produce biofuel. However, obtaining a zero tax rate for such bioethanol is possible only if the prescribed procedure with the tax bill and the intended use of bioethanol is followed.

In particular, before receiving bioethanol from the excise warehouse, the economic entity that receives it [7] issues a tax bill. However, such a bill is issued for the full tax rate, which is 133.31 hryvnias for 1 liter of 100 percent alcohol, which means that the corresponding amount of funds must be at the disposal of the manufacturing company. In the case of documentary confirmation of the fact of the intended use of bioethanol in accordance with the established procedure, the tax bill is considered repaid and the excise tax is not paid (because the zero rate is set).

If there is no such confirmation, the bank transfers the amount specified in the tax bill (at the full tax rate) to the bill holder (the DPS body). In addition, enterprises producing blended gasoline, biofuel, and other additives based on bioethanol are subject to a fine in the amount calculated based on the volume of bioethanol used for non-intended purposes and the excise tax rate increased by 1.5 times. Thus, the intended use of bioethanol is strictly controlled. If it is used for its intended purpose, a zero rate of excise tax is applied; if not as intended, the full tax rate and penalty apply.

4. Production of biomethane.

Due to the above-mentioned barriers in the production of thermal and electrical energy from biomass, the production of biomethane is becoming increasingly important. In particular, thanks to the adopted Law of Ukraine «On Amendments to Certain Laws of Ukraine Regarding the Development of Biomethane Production» [8], which entered into force in 2021, legislative prerequisites for the development of biomethane production have been created. The said Law introduced the concept of «biomethane» into the legislation of Ukraine, which means biogas that, according to its physical and chemical characteristics, meets the requirements of legal acts for natural gas for supply to the gas transportation or gas distribution system or for use as motor fuel. The law also establishes the grounds for creating a biomethane register, the procedure for issuing guarantees of origin of biomethane and further operations with them.

In order to implement the specified law, the Resolution of the Cabinet of Ministers of Ukraine «On Approval of the Procedure for the Operation of the Biomethane Register» [9] dated July 22, 2022, №. 823, was adopted, which defines the procedure for creating the biomethane register, its functional capabilities, deadlines and the procedure for submitting information to it, creating an accounting record of the biomethane producer, as well as other issues of functioning of the biomethane register. The biomethane register is an electronic accounting system designed to register the amount of biomethane submitted to the gas transportation or gas distribution system and withdrawn from the gas transportation or gas distribution system, as well as for the formation of guarantees of biomethane origin, their transfer, distribution or cancellation, and the provision of biomethane origin certificates. The creation of an account in the biomethane register is carried out after an independent audit of the biomethane production facility, which confirms its ability to produce biomethane.

In January 2023, the State Energy Efficiency Agency announced the start of the biomethane registry [10]. In addition, the requirements regarding the oxygen content in biomethane when supplying it to gas transmission and gas distribution networks have been changed (maximum 0.2 percent for gas transmission and no more than 1.0% for gas distribution networks) [11]. All these regulatory changes will contribute to the emergence of the first production of biomethane in Ukraine already this year.

Although the law currently regulates mostly the case of biomethane production with its subsequent supply to gas networks, the issue of legislative regulation of the use of liquefied or compressed biomethane with obtaining guarantees of origin is also being considered, for which it is necessary to amend the Law of Ukraine «On Alternative Fuels».

5. Use of digestate produced in biogas plants.

In November 2022, the Law of Ukraine «On Amendments to Certain Laws of

Ukraine Regarding the Improvement of State Regulation in the Field of Handling Pesticides and Agrochemicals» [12] was adopted, which entered into force in June 2023, and which introduces the concept of «digestate» into the legislation of Ukraine. According to the mentioned law, the digestate produced in biogas plants is the remains of raw materials, by-products and waste of animal or plant origin, in a mixture or not, formed as a result of a controlled process of anaerobic fermentation with the release of biogas, which meets the requirements established by the Regulation (EC) 2019/1009 of the European Parliament and of the Council of June 5, 2019 on establishing rules for placement on the EU fertilizer market and amending Regulations (EC) 1069/2009 and (EC) 1107/ 2009 and repealing Regulation (EC) 2003/ 2003. The main provision of this law for the bioenergy sector is the third part of the fourth article, which stipulates that the digestate produced in biogas plants, which is used as an organic fertilizer or soil improver, is not subject to the requirements for state registration of pesticides and agrochemicals.

Thus, the sector of energy production from biomass in Ukraine is regulated by a significant number of laws and by-laws. In addition, since the sector is constantly developing, this is reflected in the legal regulation, which is periodically improved.

According to the World Bioenergy Association, the global energy supply is dominated by fossil fuels – coal, crude oil and natural gas, the share of which in 2020 was 80% of the total supply of primary energy. The share of renewable energy in 2020 was only 15% in primary energy supply, which is 0.9% more than in 2019. In total, 95.78% of all renewable energy in 2020 was produced from bioenergy with a small share of geothermal and solar thermal technologies (4% and 0.22%, respectively). Among the main sources of bioenergy, the main place is occupied by biomass (Table 1, Fig. 1) [13].

The bioenergy sector is a branch of electricity, the basis of which is the production of biofuels from biomass. Today, bioenergy occupies a significant share of the world's renewable energy, playing an important role in replacing fossil fuels and reducing greenhouse gas emissions. In 2020, 95.78% of all renewable energy in the world was produced from bioenergy, with a small share of geothermal and solar thermal technologies (4% and 0.22%, respectively).

Table 1. Total primary energy supply in the world, 2010-2020, EJ

Types of fuel	Years							Deviation 2020/2010
	2010	2015	2016	2017	2018	2019	2020	
Coal	153,0	161,0	156,0	158,0	162,0	162,0	157,0	4,0
Oil	173,0	182,0	184,0	186,0	187,0	187,0	172,0	-1,0
Natural gas	114,0	122,0	127,0	130,0	137,0	141,0	138,0	24,0
Nuclear fuel	30,1	28,1	28,5	28,8	29,6	30,5	29,2	-0,9
Renewable energy sources	66,3	75,1	80,6	81,1	83,0	85,4	88,0	21,7
Total	536,4	568,2	576,1	583,9	598,6	605,9	584,2	48,0

Source: calculated by the author according to data from the World Bioenergy Association (WBA) [13]

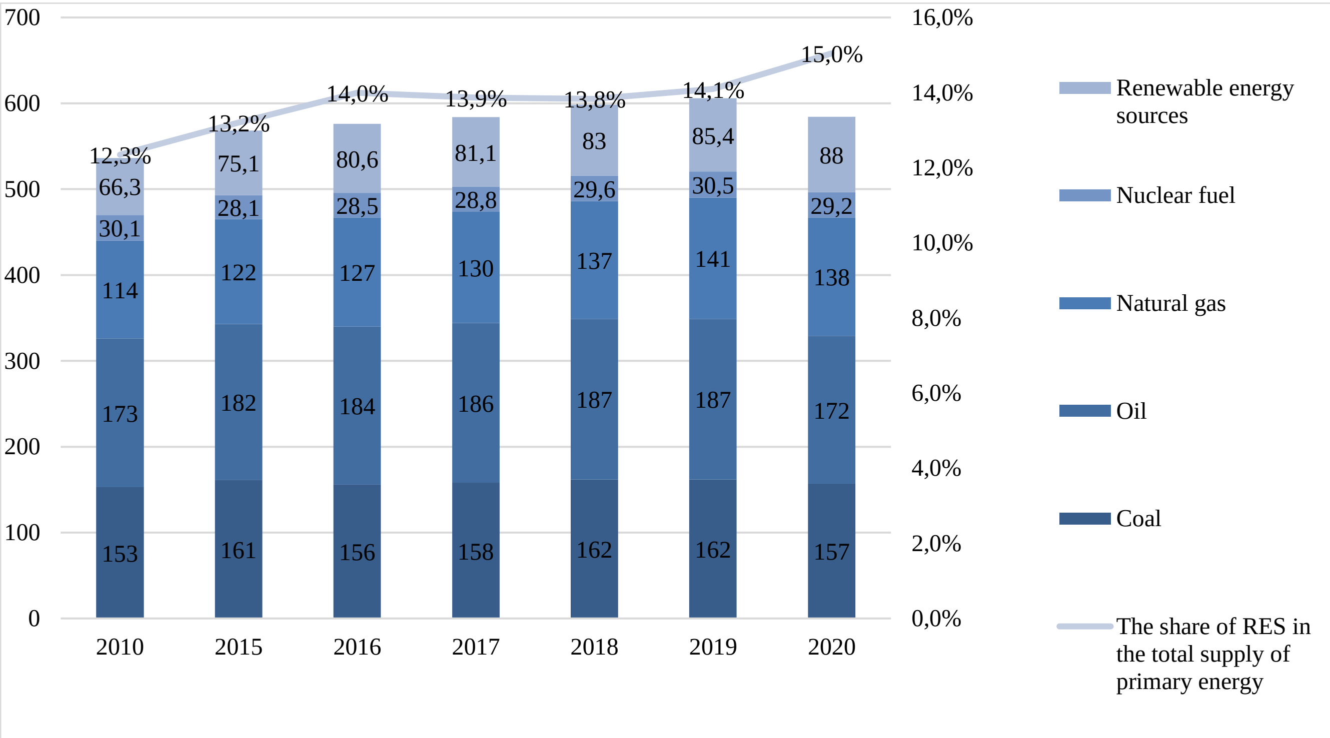

Fig. 1. Total supply of primary energy in the world, 2010-2020, EJ

Source: calculated and constructed by the authors according to the data of the World Bioenergy Association (WBA) [13]

Agriculture is a key sector for increasing the potential of bioenergy use in the future. As for yields of major crops, there is considerable potential to increase yields in various regions of the country to the world average. This will increase the production of both food and fuel, and the agricultural sector will be a key factor in increasing the use of bioenergy worldwide.

Biomass – biologically renewable substances – agricultural and forest waste, organic residues of household and industrial waste, as well as energy plants. Biomass, which is regularly grown and its use as an energy source is not accompanied by a reduction in green vegetation, is recognized as a renewable resource and is considered ecologically neutral (has a zero balance of carbon dioxide emissions).

In the directive of the European Parliament and the Council of Europe 2009/28/EC on the promotion of the use of energy produced from renewable sources, biomass is considered a substance of organic origin that undergoes biological decomposition – products, waste and residues of agriculture (including substances of plant and animal origin), forestry economy and related industries, taking into account fish farming, as well as a part of industrial and household waste that undergoes biological decomposition [14].

According to the definition of biomass given in the Law of Ukraine «On Alternative Fuels», biomass is a biologically renewable substance of organic origin that undergoes biological decomposition (waste from agriculture (plant and animal husbandry), forestry and technologically related industries, as well as the organic part of industrial and household waste [2].

According to the Bioenergy Association of Ukraine [15], in 2020, about 5.2 billion m^3 of natural gas was replaced by biomass, which is approximately 15% of the total pre-war consumption. For energy production, up to 30% of the theoretical potential (i.e., the total volume of formation) of grain crop straw and up to 40% of the theoretical potential of waste from the production of corn for grain, sunflower, and rapeseed straw can be used.

For Ukraine, bioenergy is one of the strategic directions for the development of the renewable energy sector, given the country's high dependence on imported energy sources, primarily natural gas, and the great potential of biomass available for energy production. Unfortunately, the rate of development of bioenergy in Ukraine is still significantly behind the European ones. Today, the share of biomass in gross final energy consumption is 1.78%. Almost 2 million tons of biomass of various types are used annually for energy production in Ukraine [10].

The sources of biomass are residues and waste from agriculture and forestry, the woodworking and pulp and paper industries, the food industry, and utilities, as well as specially grown energy crops that give a rapid increase in green mass (willow, poplar, etc.), certain varieties of grasses plants (miscanthus, millet, sorghum, etc.). Energy crops also include sunflower, rapeseed, corn, and sorghum.

Agriculture can be a source of a large volume of different types of biomass for energy cellars. In particular, this is the straw of grain and other crops, waste from the production of corn for grain and sunflower. The most common areas of biomass use include the production of thermal and electrical energy from solid biofuels, biogas and biomethane, as well as the production of motor biofuels (biomethane, biodiesel, bioethanol).

During the period of 2010-2022, the production of the main agricultural crops in Ukraine constantly increased (with the exception of 2020 and 2022 due to the conduct of military operations on the territory of the country), and this trend in the future guarantees the generation of a large amount of waste suitable for use as fuel (Table 2).

Table 2. Selected indicators of agricultural production in Ukraine during 2010-2022

Indicator	Years						Deviation, 2022/2010
	2010	2015	2019	2020	2021	2022	
Gross collection, thousand tons							
Cereal and leguminous crops, including:	39270.9	60125,8	75143,2	64933,4	86010,4	53863,7	14592,8
- wheat	634,5	594,7	664,3	618,0	782,1	822,5	188
- barley	5265,9	5007,2	5038,3	4345,0	4581,3	2944,9	-2321
- corn	11953,0	23327,6	35880,1	30290,3	42109,9	26186,9	14233,9
Sunflower	6771,5	11181,1	15254,1	13110,4	16392,4	11328,8	4557,3
Turnip	1469,7	1737,6	3698,7	2557,2	2938,9	3318,0	1848,3
Sown areas, thousand ha.							
Cereal and leguminous crops, including:	14575,7	14640,9	15291,9	15282,9	15948,4	11772,9	-2802,8
- wheat	302,0	169,4	167,1	166,7	187,1	216,5	-85,5
- barley	1880,0	1767,9	1552,4	1367,0	1334,9	933,7	-946,3
- corn	2647,6	4083,5	4986,9	5392,1	5481,8	4124,5	1476,9
Sunflower	4572	5105	5928	6457	6622	5293	721
Turnip	907	682	1282	1127	1311	1186	279

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Productivity, c/ha							
Cereal and leguminous crops, including:	26,9	41,1	49,1	42,5	53,9	45,8	18,8
- wheat	21,0	35,1	39,8	37,1	41,8	38,0	17,0
- barley	28,0	28,3	32,5	31,8	34,3	31,5	3,5
- corn	45,1	57,1	71,9	56,2	76,8	63,5	18,3
Sunflower	14,8	21,9	25,7	20,3	24,8	21,4	6,6
Turnip	16,2	25,5	28,9	22,7	22,4	28,0	11,8

Source: summarized by the authors based on the data of the State Statistics Service of Ukraine [16]

Part of agricultural residues and waste is immediately used to meet the needs of agricultural enterprises – as organic fertilizer, bedding or animal feed, etc.), part – by other sectors of the economy, and the rest of the biomass is not used, it is often burned in the fields or taken to landfills, which brings significant ecological damage to the environment. Part of the unused biomass is advisable to be used for energy production, but it is important to determine what proportion of agricultural waste and residues can be used for energy needs without a negative impact on soil fertility.

In their own research, scientists of the Bioenergy Association of Ukraine [17; 18], determine the bioenergy potential of the agricultural sector based on the determination of the theoretical, technical and economic potential of agricultural waste and energy crops:

1) theoretically possible (theoretical) – the total maximum amount of biomass that can theoretically be used for energy production. In the case of waste and residues, the theoretical potential is equal to the maximum amount of waste and residues (eg straw) generated;

2) technically available (technical) – indicates what share of the theoretical potential is physically available at the current level of technical and technological development (for example, the volume of straw that can actually be collected);

3) economically expedient (economical) – indicates that part of the technical potential that satisfies the criteria of economic expediency and takes into account the interests of other consumers of this type of biomass.

The method of determining the bioenergy potential of agriculture is one of the most important criteria in the study of bioenergy, as it primarily determines the assessment of the economic feasibility of developing and using a particular energy source.

The technical potential is calculated from the theoretical using the coefficient of technical availability, which determines the proportion of plant residues, waste and other types of biomass that can actually be collected (ie is available) for further processing/use. The economic potential is calculated from the technical using the coefficient of energy use, which determines the share of plant residues, waste and other types of biomass that can be used for energy production [19, p. 202].

For agricultural waste, the theoretical biomass potential is equal to the total volume of residues. For energy crops, this is the maximum amount of biomass that can be obtained with theoretically optimal management of agriculture, taking into account the limitations arising from temperature, solar radiation and precipitation [20].

To assess the theoretical bioenergy potential of Ukraine’s agricultural industry, we will use the methodology of the Bioenergy Association of Ukraine, in which the key aspects are the waste coefficients for each crop, as well as the share of waste that can be used for energy production.

To calculate the potential of straw and other plant residues, waste coefficients were used according to the data of the Crop Production Department of the National Academy of Agrarian Sciences of Ukraine. Waste coefficients are the ratio of the dry mass of ground residues to the mass of the harvested crop with field moisture. For example, for grain crops, ground residues are straw, and the harvest is grain [21, p. 61]. The waste ratio for wheat is – 1.0; for barley – 0.8; for other cereals – 1.0; for corn per grain – 1.3; for sunflower – 1.9; for rapeseed– 1.8.

The primary task for determining the bioenergy potential of Ukraine's agricultural sector is the calculation of the theoretical potential of biomass in Ukraine. The volumes of the main primary plant waste generated in the agriculture of Ukraine during 2010-2022 are presented in the table. 3.

The calculation of the bioenergetic potential of the straw of grain, technical, and cereal crops was performed for the most common types of crops that are grown: wheat, rye, barley, oats, millet, corn (stalks), soybeans, sunflower (stalks), buckwheat, as well as rapeseed (straw).

It is calculated in the table. 3 values are the theoretically available volume of waste for energy production in Ukraine. For a better understanding, the calculated theoretical potential in natural indicators must be translated into conventional fuel. To translate the obtained natural indicators into conventional fuel, the value of heat of combustion of conventional fuel was used, which is equal to 29.3 MJ/kg (7000 kcal/kg) (Table 4) [22, p. 175].

Table 3. Volumes of primary plant waste in Ukraine during 2010-2022

Agricultural crops	Coefficient of waste generation	Years								Deviation, 2022/2010
		2010		2015		2021		2022		
		Gross harvest of grain, thousand tons	Volume of generated waste, thousand tons	Gross harvest of grain, thousand tons	Volume of generated waste, thousand tons	Gross harvest of grain, thousand tons	Volume of generated waste, thousand tons	Gross harvest of grain, thousand tons	Volume of generated waste, thousand tons	
Wheat	1,0	16851,3	16851,3	26532,1	26532,1	32151,0	32151,0	20729,2	20729,2	3877,9
Barley	0,8	8484,9	6787,9	8288,4	6630,7	9437,0	7549,6	5608,2	4486,6	-3998,3
Rye	1,3	464,9	604,4	391,1	508,4	593,1	771,0	314,0	408,2	-56,7
Millet	0,8	117,1	93,7	213,2	170,6	205,0	164,0	90,6	72,5	-44,6
Oat	1,0	310,8	310,8	210,5	210,5	178,0	178,0	153,5	153,5	-157,3
Buckwheat	1,9	133,7	254,0	128,1	243,4	105,8	201,0	147,7	280,6	146,9
Other legumes	0,7	592,3	414,6	502,1	351,5	680,6	476,4	334,2	233,9	-358,4
Soy	0,9	1680,2	1512,2	3930,6	3537,5	3493,2	3143,9	3434,8	3091,3	1411,1
Turnip	2,0	1469,7	2939,4	1737,6	3475,2	2938,9	5877,8	3318,0	6636,0	5166,3
Corn for grain (stalks)	1,3	11953,0	15538,9	23327,6	30325,9	42109,9	54742,9	26186,9	34043,0	22090,0
Sunflower (stems)	1,9	6771,5	12865,9	11181,1	21244,1	16392,4	31145,6	11328,8	21524,7	14753,2

Source: calculated by the authors based on the Letter of the National Academy of Agrarian Sciences of Ukraine № 5–2/256 dated November 16, 2012 and the State Statistics Service of Ukraine [16]

According to the calculations, the theoretical energy potential of primary crop production waste in Ukraine during 2010-2022 ranged from 29,415.7 thousand t.e. in 2010, up to 66,267.0 thousand tons in 2021. We can trace a clear trend towards the growth of the total theoretical potential of crop production waste in Ukraine until 2021. In connection with the full-scale invasion, the volume of production of agricultural crops decreased significantly, therefore, the theoretical potential of primary plant waste in Ukraine in 2022 decreased to 45,425.3 thousand tons per annum.

The size of the technical potential is limited by the available harvesting technology, which leads to a decrease in the theoretical potential by the amount of the technical availability coefficient. As for the economically feasible potential, it is influenced by a number of other factors, sometimes leading to a change in its trend, which is the opposite of the trend of change in theoretical and technical potential.

In this context, the following factors can be distinguished:

1) competition between the use of waste for energy purposes and in the field of animal husbandry;

2) the possibility of depletion of organic and nutrient substances in the soil due to the removal of straw from agricultural land. These aspects are taken into account when calculating the economic potential, taking into account the coefficient of energy use.

Table 4. The theoretical potential of primary crop production waste in Ukraine, 2010-2022, thousand tons AD

Agricultural crops	Lower heat of combustion, kcal/kg	Years				Deviation, 2022/2010, +/-
		2010	2015	2021	2022	
Wheat	3285	7908,1	12451,1	15088,0	9727,9	1819,8
Barley	3190	3093,4	3021,7	3440,5	2044,6	-1048,8
Rye	3240	279,7	235,3	356,9	188,9	-90,8
Millet	3000	40,1	73,1	70,3	31,1	-9,1
Oat	3850	170,9	115,8	97,9	84,4	-86,5
Buckwheat	3000	108,9	104,3	86,2	120,3	11,4
Other legumes	3000	177,7	150,6	204,2	100,3	-77,4
Soy	3800	820,9	1920,4	1706,7	1678,1	857,2
Turnip	3660	1536,9	1817,0	3073,2	3469,7	1932,8
Corn for grain (stalks)	3270	7258,9	14166,5	25572,7	15902,9	8644,0
Sunflower (stems)	3270	6010,2	9924,0	14549,4	10055,1	4044,9
Total	-	29415,7	45994,9	66267,0	45425,3	16009,7

Source: calculated by the authors based on the data in the table. 3 and Bioenergy Association of Ukraine [15]

Table 5 contains the results of calculations of the technical and economically feasible potential of primary plant waste, which is annually formed in the process of agricultural production in Ukraine.

The calculated data show that in 2022, the greatest potential for use for energy purposes in Ukraine is waste from such agricultural crops as corn for grain – 12,530.6 thousand tons, sunflower – 9,748.1 thousand tons, wheat – 2,489.5 thousand tons, rapeseed – 2,151.3 thousand tons. and soybeans – 1194.7 thousand tons. The analysis of the obtained data shows that the theoretical potential varies depending on the year and mainly depends on the yield of agricultural crops.

Technically achievable potential generally reflects the change in theoretically possible potential, although less clearly. Greater elasticity is explained by the fact that the value of the potential is also affected by the coefficient of technical availability of crops. The distribution of the energy potential of primary agricultural waste in different regions of Ukraine depends on several factors, including the area under crops and the yield of agricultural crops in each district [23, p. 87].

Table 5. Technical and economic potential of primary crop production waste in Ukraine, 2010-2022, thousand t u.p.

Agricultural crops	Technical potential					Economic potential				
	Coefficient of technical availability of waste	Years				Coefficient of energy use of waste	Years			
		2010	2015	2021	2022		2010	2015	2021	2022
Wheat	0,5	3954,0	6225,6	7544,0	4864,0	0,33	1304,8	2054,4	2489,5	1605,1
Barley	0,5	1546,7	1510,9	1720,2	1022,3	0,33	510,4	498,6	567,7	337,4
Rye	0,5	139,9	117,7	178,4	94,5	0,33	46,2	38,8	58,9	31,2
Millet	0,5	20,1	36,5	35,1	15,5	0,33	6,6	12,1	11,6	5,1
Oat	0,5	85,5	57,9	49,0	42,2	0,33	28,2	19,1	16,2	13,9
Buckwheat	0,5	54,4	52,2	43,1	60,1	0,33	18,0	17,2	14,2	19,8
Other legumes	0,5	88,8	75,3	102,1	50,1	0,33	29,3	24,9	33,7	16,5
Soy	0,7	574,6	1344,3	1194,7	1174,7	1	574,6	1344,3	1194,7	1174,7
Turnip	0,7	1075,8	1271,9	2151,3	2428,8	1	1075,8	1271,9	2151,3	2428,8
Corn for grain (stalks)	0,7	5081,2	9916,6	17900,9	11132,1	0,7	3556,9	6941,6	12530,6	7792,4
Sunflower (stems)	0,67	4026,8	6649,1	9748,1	6736,9	1	4026,8	6649,1	9748,1	6736,9
Total	-	18657,9	29272,8	42687,9	29643,2	-	13187,6	20887,0	30837,4	22183,9

Source: calculated by the authors based on the data in the table. 4 and the Bioenergy Association of Ukraine [15]

Despite the significant bioenergy potential of the agro-industrial complex in

Ukraine, there are also a number of barriers that prevent the development of this direction of biomass use and slow down the pace of achieving energy independence of the industry. The main ones, in our opinion, are:

1) insufficient level of development of the solid biofuel market;

2) minimum volumes of state support for producers of biomass and biofuels;

3) lack of auctions for state support of renewable energy production projects;

4) impossibility of obtaining a «green» tariff for new producers of electricity from biomass and biogas that started work on January 1, 2023;

5) the need to pay a tax for carbon dioxide emissions for boiler plants, CHP plants, thermal power plants that operate on biomass;

6) the need for mandatory state registration of digestate obtained from biogas plants for the purpose of its use as organic fertilizer.

Thus, in order to overcome the barrier of the insufficient level of development of the solid biofuel market, it is necessary to introduce a system of electronic trade in solid biofuel through the use of electronic auctions, which guarantee the quality of biofuels [24].

By overcoming the second barrier, the minimum amounts of state support for producers of biomass and biofuels, we see the expansion of the amounts of state support for agricultural producers, provided that they produce biomass or biofuels and implement bioenergy projects in production.

The possibility of overcoming the third barrier to the development of bioenergy in Ukraine consists, accordingly, in the initiation of auctions for state support of projects for the production of electricity from RES.

The impossibility of obtaining a «green» tariff for producers of electricity from biomass and biogas who started their activities after 01.01.2023 can be solved by giving all producers of electricity from biomass and biogas the opportunity to choose between receiving a «green» tariff and participating in auctions.

Overcoming the last, sixth barrier we identified is to cancel the requirement for mandatory state registration for digestate, as well as to develop and approve a national standard for digestate when using it as an organic fertilizer or soil improver

Energy dependence of Ukraine, especially dependence on Russian natural gas (even if it is bought through intermediaries from the EU) is one of the biggest threats to national security.

Replacing natural gas with biomass waste is the easiest and cheapest way to get rid of this dependence.

We compare the prices of the main types of fuel and energy in Ukraine (Table 6).

Table 6. Comparison of the cost of a unit of energy in energy carriers in Ukraine, November 2022

Type of fuel or energy carrier	Average price with transport and VAT		Lower calorific value		The cost of a unit of energy, UAH/GJ with VAT
	A		B		A/B
Natural gas for households	7420	UAH/thousand m^3	33.5	MJ/ m^3	221
Natural gas for the budget sector	16500	UAH/thousand m^3	33.5	MJ/ m^3	492
Natural gas for industry	40000	UAH/thousand m^3	33.5	MJ/ m^3	1194
Coal	10800	UAH /ton	25	MJ/kg	432
Oil fuel	26000	UAH /ton	42	MJ/kg	619
Electricity for households	1.68	UAH/KW*h	-		467
Electricity for non-household consumers	6.0	UAH/KW*h	-		1666
Electricity for non-household consumers through a heat pump with SOR=2.7	6.0	UAH/KW*h	-		617
Wood chips (W=40%)	2500	UAH /ton	10.5	MJ/kg	238
Wood pellets	9000	UAH /ton	17	MJ/kg	529
Pellets from husk	7000	UAH /ton	17.5	MJ/kg	400
Straw bales or corn stalks (W=15%)	2000	UAH /ton	14.6	MJ/kg	137

Their values are given in the first column. In the second – calorific value. And in the third – the ratio of the indicator of the first column to the second, which shows the cost of a unit of energy in this fuel. It is correct to compare according to the third indicator. As can be seen from the table, the most expensive for the consumer will be heating with electricity and natural gas for industry. The cheapest is wood chips and bales of straw or corn stalks.

All types of solid biofuels are competitive with natural gas for industry, and almost all (except wood pellets) are competitive with natural gas for budget organizations. However, solid biofuels are practically not competitive with gas for the population. And the issue here is not the high cost of biofuels, but non-market subsidization of the cost of gas for the population by approximately 5 times, in relation to its market price.

The energy potential of biomass in Ukraine, according to BAU estimates, is about 21.2 million tons of oil equivalent per year, which is equal to 26 billion m^3 of gas. In Europe, 60% of renewable energy comes from biomass, and 40% comes from hydropower, sun, wind and other sources. In Ukraine, this ratio is even higher – currently biomass makes up about 75% of all RES [25].

We will analyze the energy potential of biomass in Ukraine (Table 7).

Table 7. Energy potential of biomass in Ukraine (2021)

Type of biomass	Theoretical potential, million tons	Potential available for energy (economic)	
		share of theoretical potential, %	million tons of oil equivalent
Straw of grain crops	42.0	30	4.31
Rapeseed straw	5.3	40	0.72
By-products of the production of corn for grain (stalks, rods)	54.7	40	4.18
By-products of sunflower production (stems, baskets)	31.1	40	1.79
Secondary agricultural waste (sunflower husks)	2.8	100	1.16
Wood biomass (fuel, sawdust, woodworking waste)	7.2	95	1.68
Wood biomass (dry matter, wood from protective forest strips, waste from pruning and uprooting of perennial agricultural plantations)	8.8	45	1.02
Biodiesel (from rapeseed)	-	-	0.41
Bioethanol (from corn and sugar beet)	-	-	0.93
Biogas from residues and by-products of the agro-industrial complex	2.8 billion m^3 CH_4	42	0.99
Biogas from solid household waste landfills	0.6 billion m^3 CH_4	29	0.14
Biogas from wastewater (industrial and municipal)	0.4 billion m^3 CH_4	28	0.09
Energetic plants:			
- willow, poplar, miscanthus (1 million ha)	11.5	100	4.88
- corn for biogas (1 million hectares)	3.0 billion m^3 CH_4	100	2.57
Total	-	-	24.87

In total, it amounts to 24.87 million tons of oil equivalent, which is about 29% of the total energy supply in Ukraine (86.36 million tons of oil equivalent in 2020). As an agrarian state, this potential consists mainly of biomass of agrarian origin. About 49% of it is made up of harvest tailings. Moreover, 30% of the total amount of straw available for energy production was used for the calculation, leaving 70% for returning to the soil and for other traditional uses of straw. For other harvest residues (corn and sunflower stalks), this share is taken as 40%. With such relatively small shares of energy use of crop residues, it is possible to ensure a balance between the energy use of biomass and its return to the soil. Successful recommendations are also provided by many domestic and foreign scientists.

The main components of the energy potential of biomass are waste and by-products of agriculture (agricultural residues – 9.4 million tons of oil equivalent, or 43% of the total potential) and energy plants (7.5 million tons of oil equivalent, 34%), which is collectively defined by the term agrobiomass. At the same time, the largest shares of the potential of agricultural residues fall on the straw of cereal grain crops (36%) and by-products/waste from the production of grain corn (corn cobs – 33%).

Despite certain fluctuations, the amount of biomass of agricultural origin in Ukraine increases almost every year due to the general trend of growth in the production and yield of the main agricultural crops. For example, in 2019, record harvests of sunflowers, corn for grain, and some other grain crops were harvested in the country over the past 20 years. Over the period since 2000, the energy potential of the straw of cereal grain crops, by-products and waste from the production of corn for grain and sunflower in Ukraine has increased three times – from 2.8 million tons of oil equivalent in 2000, up to 8.5 million tons of oil equivalent in 2020.

The contribution of wood biomass to the energy potential is relatively small – about 2.6 million tons of oil equivalent/year, or 12% of the total volume. This biomass can be conditionally divided into that which comes from traditional sources (firewood, cutting residues, woodworking waste) and from additional sources (dry matter, wood from the reconstruction and restoration of field protection and other protective forest strips, waste from pruning and uprooting of orchards and vineyards) [26].

The remaining components of the energy potential of biomass in Ukraine (about 10%) are liquid biofuels (biodiesel, bioethanol) and biogas obtained from various types of raw materials (waste and by-products of the agricultural industry, industrial and municipal wastewater, solid household waste).

In general, the bioenergy sector is developing dynamically in Ukraine, which is confirmed by statistical data of energy balances.

Over the past ten years, the contribution of bioenergy to the energy balance of Ukraine has increased 3 times: from 1.4 million tons of oil equivalent in 2010 to 4.2 million tons of oil equivalent in 2020. If we translate these indicators into the equivalent of natural gas, then already in 2020, Ukraine replaced 5.2 billion m^3 of natural gas/year at the expense of bioenergy. The average growth rate of the sector during these years was 11%/year. We are sure that such growth can continue for tens of years, opening up a new type of activity and profit for farmers.

The situation with the consumption of biomass for the production of energy and biofuels in Ukraine is actually the opposite of the structure of the available potential. Currently, wood biomass is most actively used (more than 90% of the economic potential), and the use of waste and by-products of agricultural origin remains at a low level. Of the various types of agrobiomass, only sunflower husks are actively used for Ukraine's energy needs – more than 70% of its potential. Energy/biofuel production from straw is at about 3% of the available potential. There are isolated examples of energy use of corn, while examples of energy production from sunflower stalks or baskets are currently unknown to the authors. On average, the energy potential of Ukraine’s biomass is used by ~11%.

A number of barriers prevent the widespread development of energy use of agricultural residues. Among them, the most significant are the lack of equipment and the lack of development of technologies for harvesting corn/sunflower stalks among agricultural producers, the complexity of organizing the "harvest-supply" chain, the general underdevelopment of the biofuel market in the country (absence of a biofuel exchange), and some others.

Analysis of the structure of biomass consumption for energy needs indicates the need for wider use of biomass of agricultural origin and energy crops. At the same time, wood biomass from so-called additional sources should be involved in this process, in particular, waste from pruning and uprooting of perennial agricultural plantations, as well as biomass from the reconstruction and restoration of field protection and other protective forest strips [27].

According to the published data of the State Statistics Service of Ukraine, the estimated volumes of biomass and biogas use by economic entities in 2020 amounted to about 1,916,000 tons of oil equivalent. (Table 8). These volumes cover the energy use of biomass for transformation into other types of fuel and energy and for final consumption (in total – 1,869,000 tons of oil equivalent).

Table 8. Consumption of fuels from biomass and biogas

Fuel consumption	In total	Lower calorific value, MJ/kg (MJ/m^3)	Energy in fuel, thousand tons of oil equivalent
Charcoal, i.e	446,5	28,9	0,3
Fuel briquettes and pellets from wood and other natural raw materials, i.e	471 771,3	16[2]	180,2
Дрова для опалення, щільн. М^3	3 865 426,0		813,7
Дрова для опалення, т (коефіцієнт перерахунку 0,7)	2 705 798,2	12,6	
Стружка і тріска деревні, т	1 009 467,8	11[2]	265,0
Інше тверде біопаливо рослинного походження, т	1 707 860,5	14[2]	570,6
Біогаз, тис. м^3	180 344,7	20	86,1
Разом			1915,9

Source: compiled according to the data of the State Statistics Service of Ukraine

Conversion into other types of fuel and energy includes the production of thermal and electrical energy, which is released to third-party consumers (thermal power plants, thermal power plants, boiler houses of centralized heat supply, etc.). Final consumption involves the use of fuel for own energy needs (for example, for heating).

These data do not take into account the energy use of biomass by households, enterprises and organizations in 2020.

According to the given estimate, firewood is the main type of fuel with a share of about 42% in the total consumption of energy from biomass and biogas by business entities (Fig. 2). In second place is «other solid biofuels of vegetable origin» (about 30%), the main part of which, according to estimates, is sunflower husks, which are formed at sunflower seed processing enterprises and are used in their raw form as fuel.

Next in terms of consumption are chips and cod (about 14%). Pressed solid fuel has a share of 9% in consumption, biogas – 5%. Such types of fuels as other solid biofuels, wood chips and chips, briquettes, pellets and biogas are used mainly for transformation into other types of fuel and energy, while the main part of firewood is used for final consumption [28].

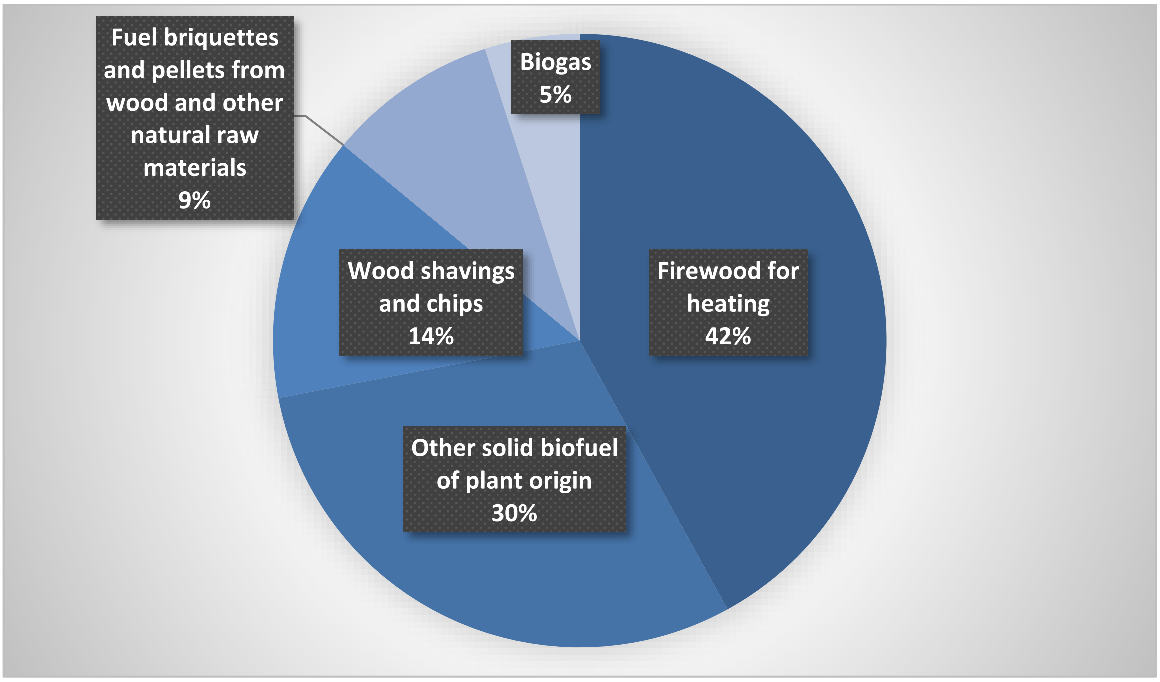

Fig. 2. The share in the total consumption of different types of fuels from biomass and biogas used by enterprises and organizations in 2020

A similar study of statistical data for the period from 2017 to 2020 shows that the volumes of final consumption of fuels from biomass remained relatively stable, while the volumes of transformation into other types of fuel and energy were constantly growing (Table 9). At the same time, the volume and share of firewood in final consumption are generally stable, but their share in transformation into other types of fuel and energy is decreasing. In the transformation sector, the volume and share of other solid biofuels of vegetable origin, as well as biogas, are growing [28].

Table 9. Energetic use of different fuels from biomass and biogas by economic entities in Ukraine in 2017-2020

Types of fuels	2017			2019			2020		
	Total	T	FC	Total	T	FC	Total	T	FC
Charcoal	1,0	0,8	0,2	0,1	0,0	0,1	0,2	0,0	0,2
Fuel briquettes and pellets from wood and other natural raw materials	129,2	102,7	26,4	172,5	149,1	23,4	170,6	150,6	20,0
Firewood for heating	823,4	337,4	486,0	859,9	327,6	532,3	804,0	311,2	492,8
Wood wool; wood flour	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Wood shavings and chips	160,8	145,9	14,8	262,9	239,4	23,4	265,0	245,0	20,0
Other solid biofuel of plant origin	377,1	341,1	36,0	445,9	413,6	32,3	543,3	502,3	41,1
Liquid biofuel	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Biogas	29,7	29,7	0,002	68,0	68,0	0,0	86,1	86,1	0,0
Total energy use	1521,2	957,7	563,5	1809,3	1197,7	611,6	1869,3	0,0	0,0

T – Transformation

FC – Final consumption

The features of the consumption of different types of biomass and biogas fuels discussed above are largely determined by the structure, scale and technical concepts of biomass energy use projects implemented in Ukraine. In particular, the predominant use of firewood, especially in final consumption, is explained by the fact that economic entities installed the cheapest available equipment for their own heating, namely wood-fired boilers. Today, quite a lot of such projects have been implemented (schools, kindergartens, hospitals and polyclinics, cultural centers and administrative buildings in villages and small towns, etc.), but all of them have a relatively small thermal capacity, as they involve heating individual, sometimes two or three located near institutions. For small projects, the installation of wood boilers was justified as the cheapest equipment option, although it requires more labor during operation. Accordingly, the resulting demand for firewood ensures its stable consumption.

The consumption of wood chips and compressed fuels mainly in the transformation sector is explained by the priority of using these fuels in larger-scale projects, for example, at thermal power plants, thermal power plants, in centralized heat supply, where mechanized fuel supply to boilers is required. However, in Ukraine, the practice of using firewood is widespread even in large projects, where its use requires additional infrastructure for unloading, storage, moving and chopping. To some extent, this is explained by the insufficient development of the Ukrainian solid biofuels market and the small number of specialized suppliers for whom the production and supply of wood chips is the main business [29].

It should be noted that the use of firewood by the population is a significant component of the energy use of biomass. You can estimate the volume of this consumption according to the State Statistics Service («Energy balance of Ukraine for 2019 (product)»). Thus, the final consumption of solid biofuels in the household sector in 2019 amounted to 77,807 TJ, which in conversion is equal to 1,857 t. e. This is almost as much as biofuel is consumed by all economic entities, according to the above-mentioned reports of the State Statistics Service «Fuel Use and Stocks».

The following opportunities exist for biofuel production in Ukraine:

- Increasing the area for growing energy crops, which include, in particular, fast-growing trees (plantations of various types of willow and poplar, paulownia) or other types of plants (sorghum, miscanthus). The economic efficiency of growing energy crops depends on their yield and costs for harvesting and processing into biofuel. Since most energy plants provide a harvest for more than one year, the initial investment in the necessary equipment and technical means, as well as the production costs, will approximately pay off in the next 2-3 years, provided that the appropriate technology and proper care of their plantations are followed. Energy crops are grown on land that is not suitable for agricultural production, therefore, it allows to preserve the soil from erosion, increase the content of the humus layer, and improve the state of the environment.

In Ukraine, only 5.4 thousand hectares of land are allocated for energy plants. At the same time, the country has from 1 to 4 million hectares of degraded and unproductive agricultural land, on which the cultivation of traditional agricultural crops is economically ineffective. Such lands can be used for growing energy plants, which are undemanding to the quality of soils and are able to restore their fertility [27].

As a result of military operations, the area of land temporarily unsuitable for productive agricultural production is expected to increase. According to expert estimates, energy plants can completely replace traditional fuel. Cultivation of energy crops even on 1 million hectares can replace half of all imported gas. The energy characteristics of agricultural crops are given in the table.

- Use of crop production waste for bioenergy production. Agricultural waste mainly consists of grain straw and residues of sunflower and corn processing. It is believed that one ton of harvested grain accounts for approximately one ton of straw. According to experts' calculations, thanks to the use of this potential in energy production, 13-15% of the state's primary energy needs can be met in the near future.

The advantages of using plant residues for the production of solid biofuel with subsequent burning to obtain thermal energy are: efficiency, environmental cleanliness of burning; convenience and long shelf life; a wide range of raw materials for production; complete readiness for use; the process can be fully automated and will require a minimum of manual labor. Anaerobic fermentation with the production of biogas is another energy direction of using crop production waste. In practice, a mixture of plant and animal waste is more often used in order to increase the yield of biogas.

- The use of sugar beet for the production of various types of biofuel, because sugar beet is a universal bioenergy crop. Both bioethanol and biogas can be obtained from sugar beet raw materials, as well as used in combination with animal manure.

A byproduct of sugar production is pulp. When processing 1 ton of sugar beets, you can get 800 kg of raw pulp or 238 kg of pressed pulp. According to calculations, if the average daily processing of beets at 1 sugar factory is 3,866 tons, then the factory can obtain 920.1 tons of pressed pulp per day. The yield of biogas (with a methane content of 70%) from 1 ton of pressed pulp is 100 m3. So, a biogas plant based on sugar factories can produce 92,010 m3 of biogas per day, and 33,583,650 m3 per year. Such installations can provide the electricity needs of the plant itself and be used for local heat networks.

- Increase of biogas plants for processing livestock waste into biogas. The list of types of raw materials used in Ukraine for biogas production is limited to 5 main types: pig manure, cattle manure, chicken manure, sugar beet pulp and corn silage. At the same time, according to the assessment of the Bioenergy Association of Ukraine (UABIO), the total potential of pulp is used by approximately 20%, pig manure – by

6%, cattle manure – by 4%, chicken droppings – by 1%. does not exceed 1–2%.

Biogas in Ukraine is produced by 51 operating biogas plants. The total gross production of biogas in 2021 is estimated at about 100 million m^3/year, and only 34% of the energy potential of this biogas has been converted into useful electrical and thermal energy. The estimated biomethane production potential of about 10 billion m^3/year is sufficient to fully cover the pre-war needs for imported natural gas and partly the needs for motor fuels.

The establishment of biomethane production can significantly reduce Ukraine's energy dependence due to its use for combined production of electricity and heat, heat supply, in industry (raw material for chemical production – nitrogen fertilizers, methanol, ammonia, etc.) and transport (motor fuel). There are also significant opportunities for its export thanks to the developed gas transportation network of Ukraine.

According to the Bioenergy Association of Ukraine, in 2021, biomass replaced about 5.2 billion m^3 of natural gas, which is approximately 15% of the total pre-war consumption.

The number of biomass power plants is a small share of the total number of biomass energy facilities, because biomass is mainly used in the production of heat. Thus, about 10% of houses in Ukraine are heated with biomass, 10% with coal, and 80% with gas.

In order to strengthen the energy sustainability of Ukraine, OJSC «Naftogaz of Ukraine» has started preparatory work on the construction of thermal power plants in Lviv and Zhytomyr that will run on biomass (wood chips) and solid secondary fuel. The total capacity of the facilities will be 90 MW of thermal energy and 11 MW of electrical energy. The planned period of commissioning of facilities in the city of Lviv – I quarter. 2023, in the city of Zhytomyr – IV quarter. 2023 [30].

JSC «Naftogaz of Ukraine» intends to build 9 bio-CHP plants and bio-boiler plants in 8 regions of Ukraine, which will have a total capacity of 250 MW of thermal energy and 52 MW of electrical energy. The company plans to become the largest heat generator from biomass by 2027, as well as replace about 2 billion m3 of natural gas.

Bioenergy is and will remain a key sector of renewable energy in Ukraine in the future. The development and implementation of bioenergy technologies makes a significant contribution to the decarbonization of the energy sector, helps the country fulfill its international obligations to reduce greenhouse gas emissions in accordance with the Paris Climate Agreement of 2015, and contributes to the implementation of the «green» energy transition of Ukraine by 2050.

The study showed that the greatest potential for energy use in Ukraine in 2022 is the waste of such agricultural crops as corn for grain – 12530.6 thousand tons of conventional fuel, sunflower – 9748.1 thousand tons of conventional fuel, wheat – 2489.5 thousand tons of conditional fuel, rapeseed – 2151.3 thousand tons of conditional fuel and soy – 1194.7 thousand tons of conditional fuel. The analysis of the obtained data shows that the theoretical potential varies depending on the year and mainly depends on the yield of agricultural crops.

Despite the significant bioenergy potential of the agro-industrial complex in Ukraine, there are also a number of barriers that prevent the development of this direction of biomass use and slow down the pace of achieving energy independence of the industry. The main ones, in our opinion, are:

1) insufficient level of development of the solid biofuel market;

2) minimum volumes of state support for producers of biomass and biofuels;

3) lack of auctions for state support of renewable energy production projects;

4) impossibility of obtaining a «green» tariff for new producers of electricity from biomass and biogas that started work on January 1, 2023;

5) the need to pay a tax for carbon dioxide emissions for boiler plants, CHP plants, thermal power plants that operate on biomass

6) the need for mandatory state registration of digestate obtained from biogas plants for the purpose of its use as organic fertilizer.

Thus, in order to overcome the barrier of the insufficient level of development of the solid biofuel market, it is necessary to introduce a system of electronic trade in solid biofuel through the use of electronic auctions, which guarantee the quality of biofuels.

By overcoming the second barrier, the minimum amounts of state support for producers of biomass and biofuels, we see the expansion of the amounts of state support for agricultural producers, provided that they produce biomass or biofuels and implement bioenergy projects in production.

The possibility of overcoming the third barrier to the development of bioenergy in Ukraine consists, accordingly, in the initiation of auctions for state support of projects for the production of electricity from RES.

The impossibility of obtaining a «green» tariff for producers of electricity from biomass and biogas who started their activities after 01.01.2023 can be solved by giving all producers of electricity from biomass and biogas the opportunity to choose between receiving a «green» tariff and participating in auctions.

Accordingly, in order to overcome the fifth barrier to the development of bioenergy in Ukraine, it is necessary to exempt installations that burn biofuel from paying the tax for carbon dioxide emissions.

Overcoming the last barrier, the sixth one we identified, consists in canceling the requirement of mandatory state registration for digestate, as well as developing and approving a national standard for digestate when using it as an organic fertilizer or soil improver.

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