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INCREASING THE RELIABILITY OF GAS SUPPLY IN UKRAINE

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Abstract. The use of alternative energy sources is one of the most important areas of modern energy policy, aimed both at improving the environment and saving traditional fuel and energy resources. The meaning of the ecological and energy optimization process is not to replace one energy source with another, but economic and industrial transformation, decarbonization and decentralization. Russian aggression has caused unprecedented destruction of the fuel and energy infrastructure of Ukraine, which has created a threat to the reliability of providing end consumers with natural gas. The article examines the processes of formation and development of the country's biomethane industry market as a response to modern global environmental and energy challenges and threats. The possibility of complete or partial replacement from a technical point of view of the traditional and most common organic fuel - natural gas - with biomethane, obtained during the disposal of waste from the agro-industrial complex, household waste, etc. to meet the needs of the housing and communal economy of Ukraine, is justified.

Keywords: natural gas, organic waste, anaerobic technology, biogas plant, biogas, biomethane, physical and chemical properties, gas supply system, reliability of gas supply

1. Formulation of the goals of the article. The use of alternative sources of energy and fuels is one of the most important areas of energy policy in the world, which is aimed at solving current problems: improving the state of the environment and reducing the consumption of traditional organic fuels [1, 2]. These issues are particularly important in Ukraine in today's conditions - the long-term military aggression of the Russian Federation, which has led to the significant destruction of the fuel and energy infrastructure of our country (in 2025 - at least a third of its own natural gas production [3]). **The purpose of this article** is to study the possibilities of partial or even complete replacement of natural gas with biomethane to regulate hourly irregularity of gas consumption or to provide end consumers with fuel, for example, in the housing and communal economy. **Statement of the problem.** After gaining independence, Ukraine inherited a huge, "voracious" industry from the point of view of energy consumption. For example, in 1991, the country used an incredible 114 billion m³ of blue fuel for its own needs, mostly of imported origin.

Over time, Ukraine has lost or modernized a significant part of its industrial facilities, and consumption has significantly decreased. Own production has practically not changed - within 20 billion m³. Today, the state no longer needs as much gas as it did in 1991. During martial law, detailed statistics on gas consumption are classified, but according to the results of 2023, Ukraine used only 19.8 billion cubic meters of gas.

Gross production of natural gas in Ukraine in 2024 amounted to 19.12 billion m³. Compared to last year, it increased by 2.2%. The main part of the fuel is consumed by the population, as well as heat producers in populated areas (communal energy enterprises) - about 11 billion m³. The share of industry in 2025 will be about 4 billion m³, and the rest (about 5 billion m³) will go to electricity production.

According to the provisions of the Energy Strategy [4], natural gas will continue to be the main

energy carrier/fuel in Ukraine. Its share is almost a third of all primary energy consumption. At the same time, it is the most ecological fuel compared to other traditional ones, including and alternative [5].

Available natural gas resources (almost all the needs of the economy were met at their expense earlier) and developed gas transportation and gas distribution networks of settlements, one of the largest underground storage systems for seasonal gas storage in Europe, contribute to the priority use of blue fuel in the state. However, the destruction of infrastructural objects of gas production, transportation and distribution systems, which is ongoing and reached its peak in the second half of 2025, imposes significant restrictions on ensuring the reliability of energy supply to end consumers [3]. Thus, there is currently a problem of maintaining the gas infrastructure in working condition and providing consumers with blue fuel. One of the ways to solve the existing problem is to replace natural gas in the future (in full or in part) with biogas of artificial origin, at least in the warm period of the year.

2. Analysis of research and publications. On an industrial scale, biogas can be obtained from several sources: waste from agricultural production (plant and animal husbandry), solid household waste landfills. Biomass is an organic substance with a certain chemical energy that can be converted into electrical energy or fuel. The source of primary biomass is terrestrial and aquatic vegetation, and the source of secondary biomass is waste, which is formed after the collection and processing of primary biomass into marketable products and is caused by the life activities of people and animals (wood, straw, vegetable waste from agriculture, animal husbandry and poultry waste, organic part of household and industrial waste). The intensification of agricultural production and the expansion of agricultural lands have led to an increase in the amount of waste and its impact on the natural environment. According to the data of statistical observations [6], of the more than 13.5 million tons of agricultural waste generated annually, the most massive are:

- 1) plant waste (7.74 million tons);
- 2) animal excrement, urea and manure (4.94 million tons);
- 3) waste of animal origin and mixed food waste (0.9 million tons).

However, statistical data do not fully reflect the real state of affairs. Thus, with a gross collection of grain at the level of 50 million tons, up to 25 million tons of straw can be formed. In the case of an increase in the gross collection to 80 million tons, the amount of straw also increases proportionally to 40 million tons. Another source of agricultural waste is animal husbandry and poultry farming, where the main type of agricultural waste is manure. There are about 13 million head of livestock in Ukraine. If, on average, one animal produces 10 kilograms of manure per day, up to 50 million tons of manure can be produced in a year. A population of 1.5 million chickens produces more than 100 tons per day. In total, about 500,000 tons of bird droppings are produced in Ukraine every year. There are also other waste products in poultry farming. According to regulations, the amount of waste can be 3.5% of the total amount per year, which amounts to 3,570 tons of biowaste based on the average weight of a bird of 500 grams.

In general, the amount of possible energy potential due to the use of renewable biomass resources in Ukraine is about 20 million t o.e./year, of which the technically available energy potential is estimated at 12 million t o.e./year; this is approximately 7% of the total consumption of primary energy resources in Ukraine. The most effective and promising basic method of utilization of livestock waste is methane "fermentation" or bimechanogenesis - a long-known process of converting biomass into energy. In the process of processing the raw material (liquid manure with a moisture content of 90-91%) by the method of methane fermentation, three primary products are formed, namely: dehydrated sludge, biogas and liquid effluents (fugate after the centrifuge). Methane "fermentation" technology allows obtaining, in addition to biogas, high-quality fertilizers and protein-vitamin feed additives (vitamin B-12, cryptogumin, etc.), and in fact, is waste-free. Therefore, in developed industrial countries, the need to build biogas plants is often determined precisely by solving environmental problems. Biogas is a combustible gas with a content of 60-80% methane, 40-20% carbon dioxide, up to 0.1% hydrogen sulfide and a small amount of nitrogen, oxygen, and hydrogen. The gas burns with a blue flame, there is no smell. The heat of combustion is within 21-23 MJ/m³. The

amount of biogas that can be obtained from 1 m³ of raw material varies between 15-17 m³/day.

The main technology, the result of which is the production of biogas, is anaerobic biotechnology, that is, fermentation of organic substances in conditions of complete absence of oxygen. Anaerobic fermentation, the development of bacteria is largely determined by the ratio of carbon C and nitrogen N. The most favorable conditions are created when the ratio C/N = 10-16. At lower values, such an amount of ammonia is formed in the fermentation process that it becomes toxic to bacteria. In the opposite case, a small amount of nitrogen limits the process of methane fermentation. For an optimal ratio, different types of waste are mixed in a bioreactor, obtaining a higher gas yield (up to 10%). Temperature is one of the most important parameters that determines the speed of the fermentation process and the productivity of the biogas plant. So, for example, an increase in temperature reduces the methane content in the total volume of biogas. At the same time, energy consumption increases. Anaerobic waste disposal technology has many advantages over aerobic:

1. 0.35 m³ of pure methane or 0.45 m³ of biogas is released for 1 kg of raw material processed with this technology under normal conditions and with a consumption of 5 kg of dry biomass per 1 m³ of water. On the scale of Ukraine, this can amount to almost 1 billion m³ of biogas annually - a full-fledged energy carrier that can replace natural gas in all cases of its use. Combustion of 1 m³ of biogas in a modern cogeneration unit gives the opportunity to obtain 2 kWh. of electricity and 4 kWh thermal energy in the form of hot water.

2. When using anaerobic fermentation, only 0.03 kg of biomass is produced in the form of waste per 1 kg of raw material. The remaining organic substances are processed into methane (that is, into biogas).

For the climatic conditions of Ukraine, in the cold period of the year, the fermentation medium should be heated, possibly using a part of the outgoing biogas, to a temperature of approximately 35 °C. Some bacteria "work" at 55 °C. They are used if it is necessary to decompose the material as quickly as possible, and not to obtain an additional amount of biogas. Increasingly, solar power plants are used as energy sources for biogas plants. Biochemical processes during fermentation take place in three stages, and each stage is provided by its own group of anaerobic bacteria.

1. Insoluble, biodegradable materials (for example, cellulose, polysaccharides, fats) are broken down into carbohydrates and fatty acids. In a working biogas generator, this happens at a temperature of 25 °C per day.

2. Acid-producing bacteria form mainly acetic and propionic acids. This stage at the same temperature also lasts a day.

3. Bacteria, forming methane, slowly, within 14 days, at a temperature of 25 °C, completely ferment the initial products, producing 70% CH₄ and 30% CO₂ with small impurities of H₂ and possibly H₂S.

Methanogenic bacteria are sensitive to the value of the pH indicator: the conditions in the environment should be moderately acidic (pH = 6.6-7.0) and, of course, not lower than 6.2. A certain content of nitrogen and phosphorus is required: about 10 and 2% of the mass of dry material, respectively. The golden rule of ensuring a successful process is to maintain constant conditions in terms of temperature and supply of starting materials. Under stable conditions, appropriate populations of bacteria suitable for these conditions can be bred. Biogas generation becomes economically justifiable when a suitable biogas generator works on the processing of an existing waste stream. Examples of such flows can be effluents from sewage systems, pig and dairy farms, meat processing enterprises, etc. Economy in this case is connected with the fact that there is no need for preliminary waste collection, organization and management of the process of their submission. It is known in advance how much and when the waste will arrive, and all that remains is to process it into biogas and fertilizers. Obtaining biogas is especially effective for agro-industrial complexes, where it is advisable to achieve the implementation of a full ecological cycle in installations of different productivity. In such complexes, manure is subjected to anaerobic fermentation followed by aerobic treatment in open pools. Biogas is used, as a rule, in cogeneration plants for the combined production of electricity and thermal energy. Algae are grown in the pools, which are fed to livestock. After aerobic fermentation, fully treated waste can be fed into artificial and natural ponds for breeding fish and waterfowl before being used as fertilizers. The success of the implementation of such schemes directly depends on the

quality of the system development of the entire project, the degree of standardization of structures, and the regularity of maintenance.

The potential of biogas production in Ukraine is about 10 billion m³/year, which will reduce carbon dioxide emissions by approximately 20 million tons/year [7] and, accordingly, reduce "thermal" environmental pollution. A biomethane plant that can produce about 10 million m³ of biomethane per year costs about EUR15 million. If you buy raw materials for EUR40/t (bales of straw or corn stalks), which will provide additional income for farmers, and sell biomethane for EUR900/1000 m³, then the profitability of such projects becomes interesting for investors - at the level of 25% profitability [7]. In Ukraine, there are more than 400 cities, 800 urban-type settlements and 25,000 villages under the control of the territorial authorities, whose local self-government bodies are fully responsible for the organization of solid waste management services. The volume of solid household waste generation in Ukraine has recently been approximately 50 million m³ every year or about 11 million tons (excluding temporarily occupied territories). Despite the fact that the population of Ukraine is constantly decreasing, the volume of household waste generation, on the contrary, is increasing.

The waste problem in Ukraine, compared to European countries, is particularly large and significant due to the dominance of resource-intensive multi-waste technologies in the national economy, as well as the lack of an adequate response to its challenges for a long time. The significant scale of resource use and the energy and raw material specialization of the national economy, together with the outdated technological base, determined and will continue to determine high rates of waste generation and accumulation. Currently, the average amount of household waste in Ukraine is 250-300 kg/year per person. The dominant method of handling household waste remains its removal and burial in landfills and landfills. Only 5.8% of generated household waste is processed, including 2.71% (1.3 million m³) is disposed of (usually incinerated), 3.09% (1.53 million m³) is sent to waste processing complexes, and about 0.003% (2000 m³) is composted. The rest, about 94%, are placed in landfills and landfills, of which there are almost 5.5 thousand in Ukraine, of which more than a third are either overloaded or do not meet the environmental safety standards in force in Ukraine. According to expert assessments, more than 99% of operating landfills do not meet European requirements. For example, Directive 1999/31/EC [8] provides for the following measures for the disposal of combustible gases:

- 1) control of accumulation and migration of landfill gas;
- 2) landfill gas must be collected at all landfills that accept biodegradable waste, as well as processed and used; if the collected gas cannot be used to generate energy, it must be burned;
- 3) collection, processing and use of landfill gas must be carried out in a way that minimizes damage to the environment or its deterioration, as well as the risk to human health.

Excessive dependence on household waste disposal can no longer be the basis of household waste management in Ukraine. In addition, signed in 2014 The Association Agreement between Ukraine, on the one hand, and the European Union, the European Atomic Energy Community and their member states, on the other [9] requires Ukraine to take immediate and decisive steps to implement European standards in the relevant field. If we compare the physico-chemical properties of biogas with the requirements for the quality of natural gases established, for example, by the Code of the Gas Transportation System [10], then without additional purification, biogas is unsuitable both for transportation through existing networks and for use by traditional gas equipment. Various methods of using such biogas are known in world practice, starting from elementary flaring directly at the place of generation without utilization of the heat of combustion products to significant purification with bringing the methane content to 90-95% (the so-called biomethane) or the production of marketable carbon dioxide [11]. Currently, in Ukraine, in the conditions of the partial destruction of the gas infrastructure, the use of biogas refined to the level of biomethane will avoid the emergency shutdown of the gas transportation and gas distribution systems, and will provide end consumers with blue fuel.

Each ton of household waste in the process of anaerobic processing of organic mass releases up to 200 m³ of biogas. In total, the state can produce up to 1 billion cubic meters of biomethane per year. And if there are practically no problems with the utilization of biomethane [11], then a significant additional amount of carbon dioxide, which is the main component of greenhouse gases - causes an

increase in "thermal" pollution of the environment. Thus, by combining the processes of electricity generation from alternative sources, wind (WES) and solar (SES) with enterprises for the production of biomethane with separate release of carbon dioxide and subsequent methanation of the obtained CO₂ with the help of "green" H₂, the following problems can be solved:

1) significantly reduce environmental pollution by agricultural production waste, solid household waste, etc. through their disposal, followed by beneficial use of the freed areas of landfills, landfills, etc.;

2) to regulate the unevenness of electricity consumption by reducing the share of thermal generation as the main method in Ukraine and, accordingly, reducing emissions of pollutants and greenhouse gases into the atmospheric air when burning coal the main fuel for thermal power plants;

3) cancel the withdrawal into reserve of nuclear power plant units that generate the cheapest electricity;

4) significantly reduce the consumption of traditional organic fuels, for example, natural gas, as well as abandon their purchase abroad.

Fig. 1 shows a schematic diagram of methane synthesis using electricity from alternative sources and carbon dioxide, which is produced during the production of biomethane.

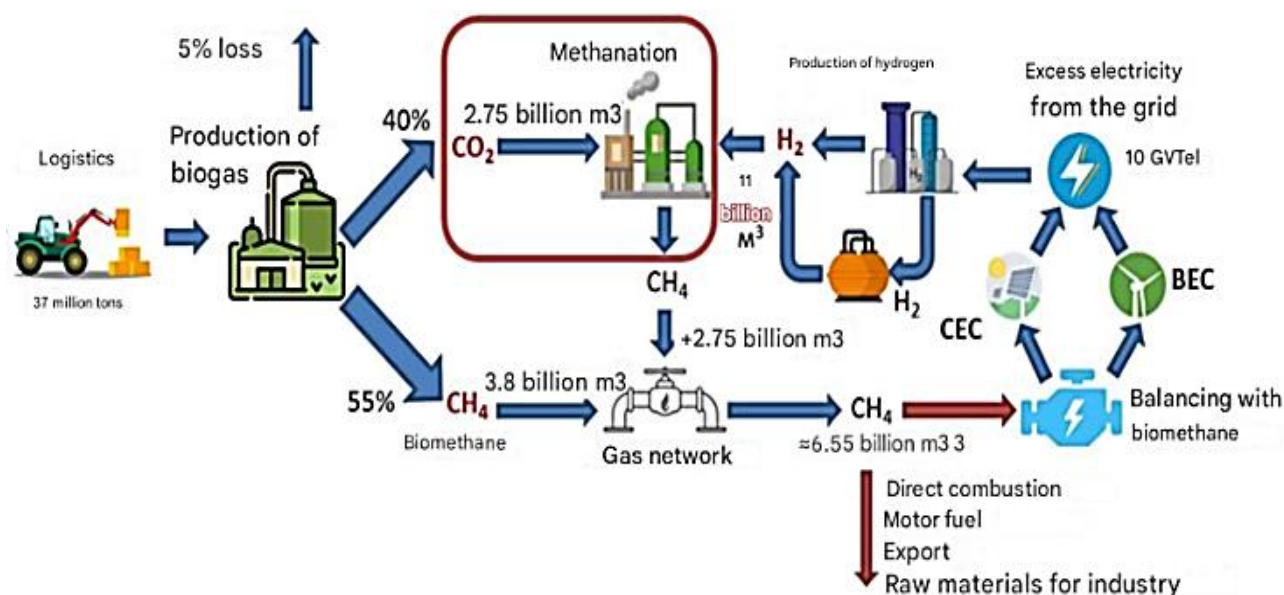


Fig. 1. Schematic diagram of carbon dioxide methanation [12]

The use of such a scheme will allow, in addition to the potential 10-11 billion m³ of biomethane in Ukraine, to annually add up to 7 billion m³ of synthetic CH₄, which can be obtained from CO₂ of biomethane plants and green H₂ with the help of electricity from alternative sources. In addition, another component of biomethane production is the fermented fraction, which contains nitrogen, phosphorus and potassium, as well as other microelements, which helps to increase soil fertility.

3.Results and discussion. The formation of the biomethane industry in Ukraine began in 2021, when the price of natural gas in Europe reached 2100 EUR/1000 m³, and the cost of biomethane production was (depending on the type of raw material) from 600 to 900 EUR/1000 m³ [13]. And therefore, at the first stages of its development, the most likely scenario is the export of the vast majority of produced biomethane to EU countries (the price of such fuel is from 1,200 to 1,500 EUR/1,000 m³). In Ukraine, currently (from an economic point of view) production is unprofitable for use on the domestic market. On the Ukrainian Energy Exchange, the weighted average price of natural gas per month for November 2025 is UAH 20,551.67 or EUR 419.64 per 1000 m³ [14].

In Ukraine, 7 biomethane plants should be operational by 2025, and investors have started construction of at least 10 more, each of which can produce 5 million m³ of gas per year. Currently,

there are about 80 biogas capacities in the state, 20 of which can be cost-effectively upgraded to biomethane (with purification from impurities: carbon dioxide, hydrogen sulfide, nitrogen, etc.) [13]. Physico-chemical properties of such gas, obtained at one of the enterprises in Khmelnytskyi region, according to the quality protocol from LLC "Operator GTS of Ukraine" according to the results of chromatographic analysis, as well as calculated in accordance with the requirements of regulatory and technical documents in force in Ukraine, are listed in Table 1.

Table 1. Biogas quality indicators [15, 16]

Indicator	Meaning
1. The content of the component, %:	
- methane	98,1251
- oxygen	0,0340
- nitrogen	1,0595
- carbon dioxide	0,6814
2. Density (20/25 °C; 0.101 MPa), kg/m ³	0,6821
3. Heat of combustion, MJ/m ³ :	
- higher	36,3990
- lower	32,8013
4. Wobbe number, MJ/m ³ :	
- higher	43,5865
- lower	48,3671
5. Content of impurities, g/m ³ :	
- hydrogen sulfide	< 0,006
- mercaptan sulfur	< 0,02
- mechanical	<0,0005

After obtaining biomethane, the question arises of determining the ways of its possible use, for example, to increase the reliability of existing gas supply systems in populated areas. The volumes of fuel generation and the regularity of its deliveries impose conditions on the methods of its transportation to consumers.

First of all, biomethane can reach settlements in rural areas, a large part of which is connected to existing high-pressure gas distribution networks (0.6-1.2 MPa) - the so-called interurban gas pipelines of network gas [17, 18]. The priority and main consumer is the population that uses gas to meet economic and household needs and heat supply needs. Large-scale industry is usually absent. Accordingly, in rural areas gasified by network natural gas, the seasonal irregularity of blue fuel consumption is characteristic: in the warm period of the year, there is no need for heat supply of buildings and structures of various purposes. Thus, in this period, gas consumption is up to 15% of the total gas consumption in the heating period. Determination of the diameters of gas distribution network pipes, calculation and selection of equipment for gas regulation units, gas metering units, etc. are performed for maximum hourly costs [17]. Accordingly, in the warm period of the year, the storage capacity of the gas distribution network can be used for fuel storage. If there are large agro-industrial holdings nearby, they can become enterprises for the generation of biogas with subsequent conversion into biomethane. In this case, it is advisable to connect the biomethane plant to the existing gas distribution network, followed by a check of the throughput capacity, if necessary, its reconstruction should be performed. In the warm period of the year, with appropriate calculations, network natural gas can be completely replaced by biomethane.

If there is no network of inter-village gas pipelines near the biomethane plant, then the best option is its transportation in a liquid state (the property of any gaseous medium is used to change its aggregate state when the temperature decreases and the pressure increases - to turn into a liquid), which makes further storage of biomethane convenient (the volume decreases in 600). Thus, an

infrastructure similar to the one for transportation, storage and use of liquefied hydrocarbon (propane-butane) gases can be created. The main difference is only in the parameters of energy carriers. In European countries, liquefied gases are the most popular compared to other types of fuels.

Such autonomous gas supply installations consist of the following structural elements: a container for storing biomethane in liquefied form (cryogenic tanks with a volume of 1 to 60 m³, depending on the mode of gas consumption), atmospheric type evaporators for regasification (in the cold season of the year - by heating), control and measuring devices, control and regulation systems.

For an individual cottage built near Kyiv for a family of 4, in which a domestic gas stove is installed to meet the household needs of the residents, a water boiler for heating and hot water supply, in the cold period of the year the total maximum hourly gas consumption will be 11, and in the warm period - 1.5 m³/h. Thus, in the warm period of the year, gas consumption is reduced by 86%. For a cottage town built with 50 similar houses, this is, respectively, 438 and 27.5 m³/h, or a reduction in consumption by 93% (taking into account the coefficients of unevenness of simultaneous operation of gas appliances and water boilers) [17].

The average volume of fuel consumption by the gas equipment of the cottage during the month in the heating/non-heating period will be, respectively, 3410/174 m³/month. In the warm season, a gas storage unit with a volume of 3 m³ with an evaporator capacity of at least 1.5 m³/h is suitable for providing an individual house. For an uninterrupted supply of gas to the consumer during the non-heating period (6 months of active consumption), it is necessary to fill the tank of the indicated volume at least once every 6 months, during the heating period - at least 2 times a month, simultaneously increasing the performance of the evaporator by installing a heater.

For a residential group in an urban-type village consisting of five 5-story buildings with 65 apartments each, the kitchens of which are equipped with instantaneous water heaters and domestic stoves, for autonomous gas supply it is necessary to connect a tank with a capacity of 60 m³ with an evaporator capacity of at least the total maximum hourly gas consumption - 170 m³/h. during round-the-clock work. Heating needs in the cold period of the year are provided from alternative sources, for example, ground source heat pump installations. During the year, the tank should be filled at least 9 times. The distance from such a gas reservoir installation when placed underground to the nearest house should be at least 40 m [17]. For backup gas supply in the event of emergency situations near the main gas regulation points, small gas distribution stations that provide fuel to settlements with a population of up to 5,000 people, it is necessary to install mobile installations with tanks with a volume of 40-60 m³, equipped with evaporators with a capacity (during round-the-clock operation) of 200 m³/hour or more.

4.Conclusions. Currently, Ukraine, despite the full-scale aggression of the Russian Federation, is implementing its strategic course - the acquisition of full membership in the European Union, which, among other things, involves the decarbonization of the economy (increasing energy efficiency, disposal of accumulated waste, development of renewable energy sources and circular economy, and synchronization with the "European Green Course" initiative). Having declared its commitment to the principles of sustainable development, Ukraine recognized that the development of renewable energy sources, reducing the consumption of traditional organic fuels, etc., are important factors in increasing the level of energy security and reducing the anthropogenic impact of the economy on the natural environment. Replacing natural gas with biomethane, obtained as a result of disposal of household waste and agricultural waste, will contribute to increasing the reliability of gas supply to end users, use of the existing potential of the gas infrastructure, continuation of its trouble-free operation, etc.

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