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# PROSPECTS FOR BIOMETHANE PRODUCTION IN UKRAINE

*Position paper No. 29 of the Bioenergy Association of Ukraine is devoted to the analysis of prospects for biomethane production in Ukraine.*

The situation regarding the development of biogas and biomethane production in Ukraine and the world is presented. Estimates of the potential of biomethane in the world, the EU, and Ukraine are given. The existing mechanisms for supporting biomethane in the EU countries are considered. The raw material base for the production of biogas/biomethane, typical for Ukraine, has been structured. Raw materials, project and product concepts of biomethane projects are described. An analysis of potential markets for biomethane consumption and technical and economic indicators of biomethane projects is given. The current legislative regulation of the biomethane market in Ukraine is described, as well as the forecast and vision of UABIO regarding the action plan for the development of the biomethane market in Ukraine until 2050.

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**Georgiy Geletukha, Petro Kucheruk, Yuri Matveev**
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[1] “Biomethane zoning and assessment of the possibility and conditions for connecting of biomethane producers to the gas transmission and distribution systems of Ukraine” ( https://saf.org.ua/library/1548/ )
[2] Global Environment Facility
[3] https://www.regatrace.eu/
[4] Project Horizon 2020 “REnewable GAs TRAde Centre in Europe” (https://cordis.europa.eu/project/id/857796 )

## Content

## Abbreviations

| | | |
|---|---|---|
| NGFS | – | Natural Gas Fuel Station |
| AFS | – | Automobile Fuel Station (Filling Station) |
| UABIO | – | Ukrainian biomass Association |
| BM | – | Biomethane |
| BMP | – | Biomethane plant |
| GTS | – | Gas Transportation System |
| GDP | – | Gas Distribution Point |
| GDS | – | Gas Distribution System |
| ICE | – | Internal Combustion Engine |
| EBA | – | European biogas Association |
| ICUR | – | Installed Capacity Utilization Ratio |
| CHP | – | Combined Heat and Power plant |
| IEA | – | International Energy Agency |
| NCSRECS | – | National Commission for State Regulation in Energy and Communal Services |
| OGTSU | – | Operator of Gas Transportation System of Ukraine |
| NG | – | Natural Gas |
| VAT | – | Value Added Tax |
| USF | – | Underground Storage Facilities of Natural Gas |
| LNG | – | Liquefied Natural Gas |
| TPP | – | Thermal Power Plant |
| CHP | – | Central Heating Plant |
| MSW | – | Municipal Solid Waste |
| DH | – | District Heating |
| CAPEX | – | Capital Expenditures |
| EUR | – | Euro |
| CNG | – | Compressed natural gas |
| Bio CNG | – | Compressed biomethane |
| FiT | – | Feed-in Tariff |
| LNG | – | Liquefied natural gas |
| Bio LNG | – | Liquefied biomethane |
| LPG | – | Liquefied Petroleum Gas |
| OPEX | – | Operational Expenditures |
| PSA | – | Pressure Swing Adsorption |
| USD | – | USA Dollars |
| SBP | – | Sugar Beet Pulp |
| WWTP | – | Waste Water Treatment Plant |
| BSG | – | Brewery`s spent grain |

## Introduction

In 2020, 15 billion $m^3$ (bcm) of biogas and 3 bcm of biomethane were produced in the EU. In 2021, the European Commission developed the REPowerEU plan [[5]], which envisages the diversification of natural gas supplies through greater imports of liquefied natural gas (LNG) and pipeline imports of natural gas (NG) from non-Russian suppliers, as well as greater production and imports of biomethane and renewable hydrogen . According to the plan, the European biomethane sector plans to produce 7 bcm of biogas and 35 bcm of biomethane in 2030. Thus, it is planned that the production of biomethane will exceed the production of raw biogas.

By the end of 2021, at least 77 biogas plants were built and had operating experience in Ukraine, of which 31 are landfill gas recovery and utilization systems at landfills, the rest are classic biogas plants operating on agricultural and industrial waste. In total, during 2021 approx. 260 million $m^3$ of biogas was obtained. Almost all biogas was used for electricity production. As of August 2022, there was no biomethane production. The Ukrainian company Gals-Agro announced plans to produce the first biomethane in Ukraine by the end of 2022. The first phase of construction involves the production of up to 330 $m^3$/h of biomethane. Later, Gals-Agro plans to increase biomethane production to 1100 $m^3$/h [[6]]. There are known plans of other biogas producers to switch to biomethane production.

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.

Ukraine has a powerful NG transit gas system, which is connected to the European NG grid. The 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 NG storage facilities. EU also has an extensive gas network with a total area of 2.2 million kilometres, to which at least two-thirds of the existing European biomethane plants are currently connected [[7]]. 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 bcm in 2020), the remaining 35% is imported [[8]]. The total amount of natural gas consumption has been constantly decreasing over the past 15 years. Replacing the consumption of natural gas with alternatives is a matter of national security, especially in the context of a military conflict and a possible complete cessation of transit of Russian NG. One of the possibilities of replacing imported NG is the production and use of biomethane.

[5] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511
[6] https://biz.liga.net/ua/all/tek/novosti/v-ukraine-do-kontsa-goda-zapustyat-pervyy-zavod-po-proizvodstvu-biometana?fbclid=IwAR0238w2RNiaP-4-pqWDvj3v2HMkfrVTGqTV26qT9WWfRmwe3-m-7Wn0ocI
[7] EBA 2021. "Statistical Report of the European Biogas Association 2021." Brussels, Belgium, November 2021.
[8] Energie of Ukraine 2021 (Енергетика України 2021). https://businessviews.com.ua/energy-of-ukraine-2021/

# Chapter 1. Biomethane market in the world: potential, production, technologies

## 1.1 Potential of biomethane production

According to the estimates of the International Energy Agency (IEA), the potential of biogas production in the world is 570 million toe (almost 680 bcm) (Fig. 1.1). The total potential of biomethane production is 730 million toe and exceeds the potential of biogas production due to the potential use of processes of thermal gasification and methanation of hydrogen obtained with the help of electrolysis (power-to-gas - P2G processes).

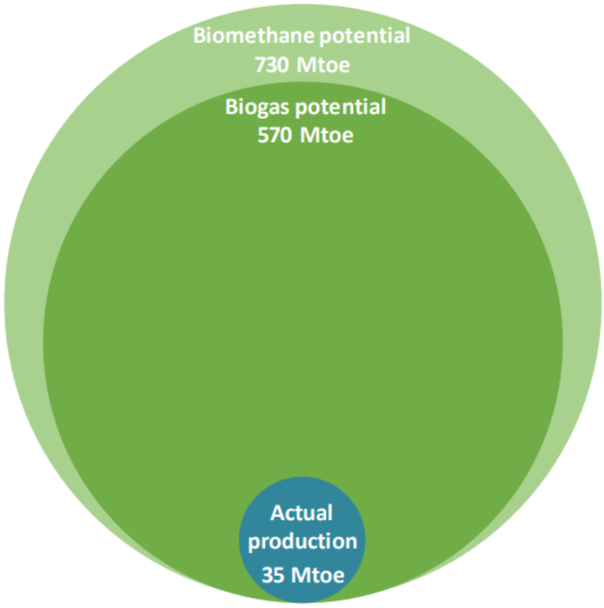


***Fig. 1.1 – Potential of biogas and biomethane production in the world***
***Source: International Energy Agency, 2018 [9]***

In a new study [10], the Gas for Climate consortium demonstrated that in the EU-27, as well as in Norway, Switzerland and Great Britain, it is possible to produce up to 41 bcm of biomethane in 2030 and already 151 bcm in 2050.

The potential of anaerobic digestion calculated in the study is 38 bcm in 2030 and should increase to 91 bcm in 2050. The main feedstock materials in 2030 will be manure (33%), agricultural residues (25%) and cover crops grown after or before the main harvest (21%). In 2050, cover crops will dominate (47%), manure (19%) and agricultural waste (17%) will be important. At the same time, industrial wastewater will form more than 10% of the potential in both 2030 and 2050.

The potential of thermal gasification for the production of synthetic methane is estimated as 2.9 bcm in 2030 and up to 60 bcm in 2050. The main raw materials in both 2030 and 2050 will be forestry residues and wood waste, which together will more than 60% of the potential.

[9] Outlook for biogas and biomethane. Prospects for organic growth https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth
[10] 2022 Biomethane production potentials in the EU https://gasforclimate2050.eu/publications/

The world production of biogas and biomethane in 2018 was about 35 million toe [11] and occupied only a small part (up to 5%) of the existing potential. Full use of the potential would correspond to replacing about 20% of the existing demand for natural gas worldwide.

## 1.2 Biomethane production development

In 2017, the global production of biomethane reached almost four bcm per annum (Fig. 1.2). The main production of biomethane was concentrated in Europe and the USA. China and India have also recently started biomethane production. Both countries as huge emerging markets have set ambitious targets for biomethane production. Brazil is also taking systematic measures to exploit its huge biomethane production potential in Central and South America [12].

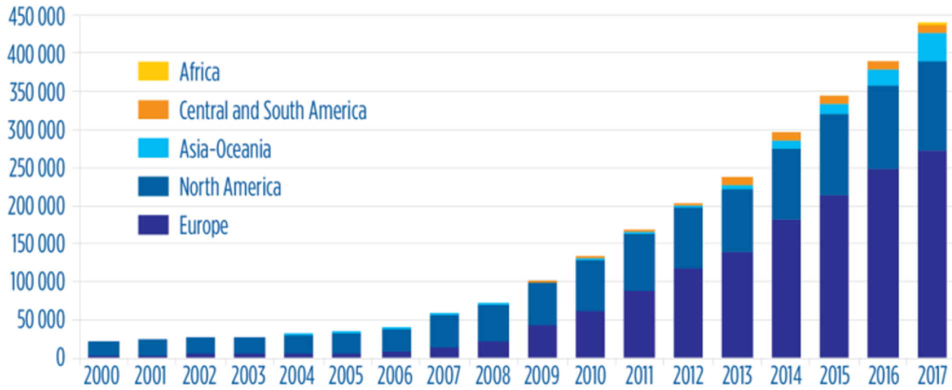


***Fig. 1.2 – Biomethane production worldwide, m³/hour (Cedigaz)***

According to the Shell Company, biomethane production in the world was 4.3 bcm/yr (3.0 million tons/year) in 2021. About 60% of biomethane was produced in European countries. But even in the EU, only 2% of the available potential is used (Fig. 1.3). In other regions, a little more than 0.5% of the available potential is used. At the same time, the total potential of biomethane production in the world, according to Shell, is 825 million metric tons (1.15 trillion $m^3$/year).

[11] World Energy Outlook. IEA. www.iea.org/weo
[12] https://www.cedigaz.org/global-biomethane-market-green-gas-goes-global/

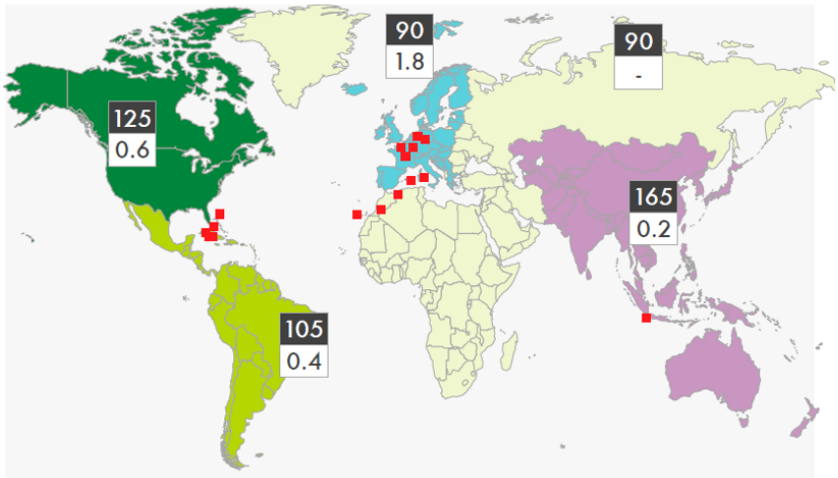


***Fig. 1.3 – Production of biomethane in the world, million tons/year (black background - biomethane production potential, white background - current production, red squares - bunkering locations) [13]***

In November 2021, the European Biogas Association (EBA) published annual statistical report, which collected information on the development of biogas and biomethane production in the EU up to and including 2020. In 2020, biomethane production in Europe already existed in 20 countries - Austria (AT), Belgium (BE), Switzerland (CH), Czech Republic (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Ireland (IE), Italy (IT), Latvia (LT), Netherlands (NL), Norway (NO), Sweden (SE), Great Britain (UK), Hungary (HU), Iceland (IS) and Luxembourg (LU).

The total number of biomethane plants (BMP) in the EU reached 880 units by the end of 2020 (Fig. 1.4). A total of 163 biomethane plants were launched in 2020, which is almost 2 times more than in 2019. It can be seen that the construction of biomethane plants is being implemented at an accelerating pace. By the end of 2021, the total number of BMP is expected to be about 1,000 units. According to the latest data from EBA 115 biomethane plants were launched in the eight months of 2021.

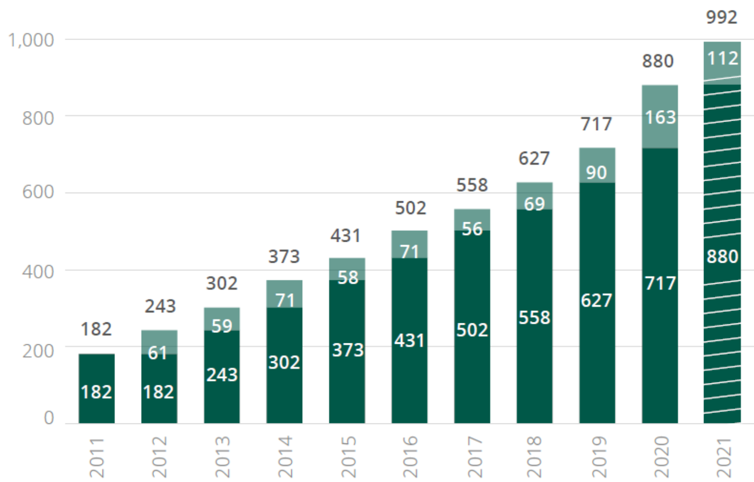


***Fig. 1.4 – Biomethane plant number in the EU [14]***

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[13] Shell LNG Outlook 2022. https://www.shell.com/promos/energy-and-innovation/v1/lng-outlook-2022-report/
[14] EBA 2021. "Statistical Report of the European Biogas Association 2021." Brussels, Belgium, November 2021. https://www.europeanbiogas.eu/eba-statistical-report-2021/

The number of biomethane plants in the EU countries in 2011-2020 is indicated in table 1.1 and in figure 1.5

***Table 1.1 – Number of biomethane plants in EU countries (EBA, 2011-2020)***

| Country | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Germany | 86 | 125 | 157 | 186 | 202 | 214 | 219 | 226 | 232 | 242 |
| France | 3 | 3 | 4 | 8 | 17 | 26 | 44 | 76 | 123 | 214 |
| Great Britain | 5 | 13 | 20 | 36 | 54 | 85 | 89 | 93 | 99 | 107 |
| Sweden | 47 | 53 | 54 | 59 | 61 | 71 | 70 | 72 | 70 | 70 |
| Netherlands | 16 | 19 | 23 | 21 | 21 | 21 | 34 | 39 | 51 | 60 |
| Denmark |  | 1 | 3 | 6 | 12 | 17 | 25 | 34 | 42 | 52 |
| Switzerland | 13 | 15 | 19 | 24 | 27 | 29 | 32 | 35 | 37 | 39 |
| Italy |  | 1 | 2 | 5 | 6 | 5 | 1 | 1 | 12 | 23 |
| Finland | 2 | 4 | 5 | 9 | 10 | 11 | 14 | 15 | 17 | 22 |
| Austria | 10 | 10 | 11 | 14 | 13 | 14 | 15 | 15 | 15 | 15 |
| Norway | 4 | 6 | 7 | 10 | 10 | 10 | 11 | 13 | 13 | 13 |
| Luxemburg | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Hungary | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Spain | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| Iceland |  |  |  |  | 2 | 2 | 2 | 2 | 2 | 2 |
| Estonia |  |  |  |  |  |  |  | 2 | 2 | 4 |
| Czech Republic |  |  |  |  |  |  |  |  | 2 | 2 |
| Belgium |  |  |  |  |  |  |  |  | 1 | 5 |
| Ireland |  |  |  |  |  |  |  |  |  | 1 |
| Latvia |  |  |  |  |  |  |  |  |  | 1 |

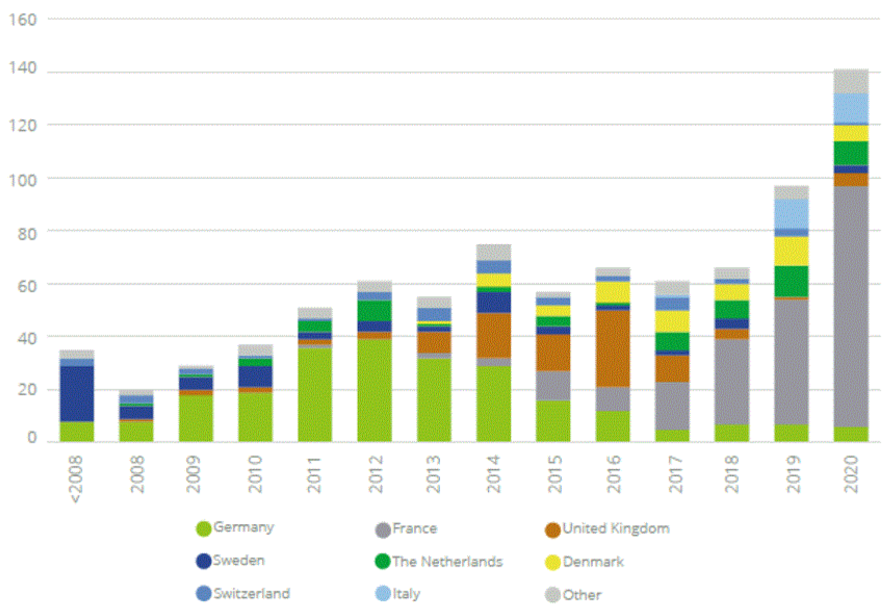


***Fig. 1.5 – Number of biomethane plants in EU countries (EBA 2021)***

Over the past nine years, the annual production of biomethane in the EU has increased 6.5 times - from 4.9 to 32 TWh (from 0.52 to 3.4 bcm/year) (Fig. 1.6) [15].

[15] The lower calorific value of biomethane is accepted as 9,4 kWh/m$^3$ (34 MJ/m$^3$)

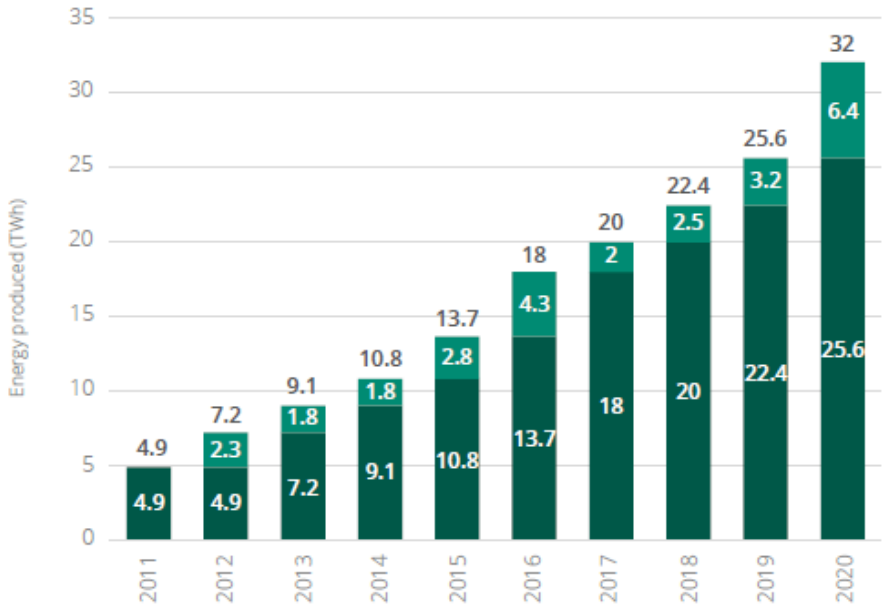


***Fig. 1.6 – Biomethane production in EU, TWh (EBA 2021)***

On average, one biomethane plant produces 36 GWh/year of biomethane (400 $m^3$ $CH_4$/h). Due to the effective support system in Europe, most biomethane plants have a relatively small average capacity in the range of 50–400 $m^3$ $CH^4$/h (Fig. 1.7).

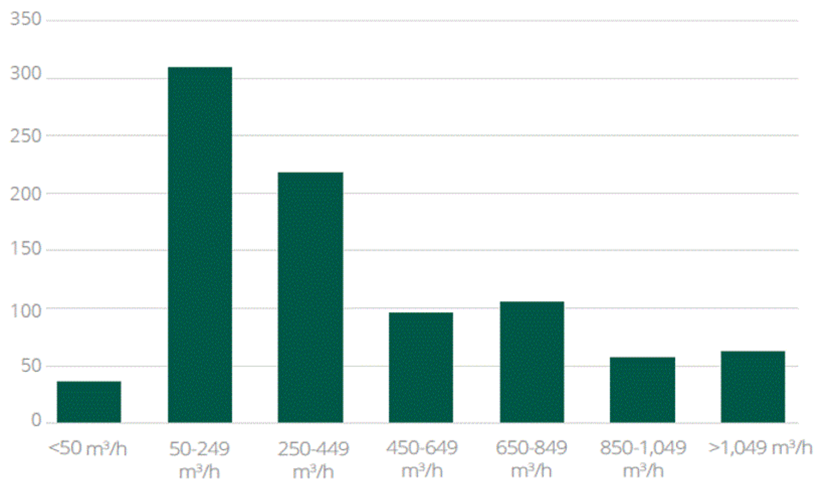


***Fig. 1.7 – Total number of active biomethane plants in the EU depending on the installed capacity***

In 2020, the largest producers of biomethane were Germany (11.2 TWh), Great Britain (6.9 TWh), Denmark (4.0 TWh), France (2.2 TWh) and the Netherlands ( 2.2 TWh).

The countries with the fastest growth in biomethane production in 2020 were the United Kingdom (1,689 GWh), Denmark (1,374 GWh), France (972 GWh), Italy (805 GWh) and the Netherlands (698 GWh).

**France** is currently the country with the fastest growing biomethane production sector in Europe. At the end of 2020, 861 biogas plants and 214 biomethane plants were operating in the region. A total of 91 biomethane plants started operating in 2020, and another 81 plants were built between January and July 2021. Another 950 projects are at various stages of development, the total capacity of which is 22.6 TWh/year.

**Italy** is second only to Germany in both the number of biogas plants and total biogas production with 1,710 biogas plants in operation and a total biogas production of 23 TWh in 2020. Italy is the second fastest growing biomethane market in Europe after France. The Italian biomethane sector grew from 12 plants in 2019 to 23 plants at the end of 2020. Italy has set a target of 2.6 bcm/year of biomethane by 2026. Forecasts show that Italy will become one of the leading producers of liquefied biomethane (bio-LNG) in Europe. In 2021, four bio-LNG plants started operating in Italy, and another 32 plants are in various stages of development; all of them should be operational between 2021 and 2023. With 1,466 compressed natural gas (CNG) filling stations, 103 liquefied natural gas (LNG) filling stations and more than 1 million CNG vehicles in 2020, Italy is the European country with the most extensive network of gas filling stations and the largest vehicle market operating on gas.

## 1.3 Plans and forecasts for biomethane market development

According to IEA estimates, the annual production of biomethane in the world can reach 200 million toe. (240 bcm/year) in 2040 in case of implementation of the sustainable development strategy (Fig. 1.8). Maintaining existing policies could lead to the production of 75 million toe of biomethane At the same time, the EU may lose its role as a world leader in the production of biomethane, since more than 50% of biomethane can be obtained and used in China and India. The total annual production of biomethane in China and India may amount to 25-55 million toe in 2030 and up to 40–110 million toe in 2040.

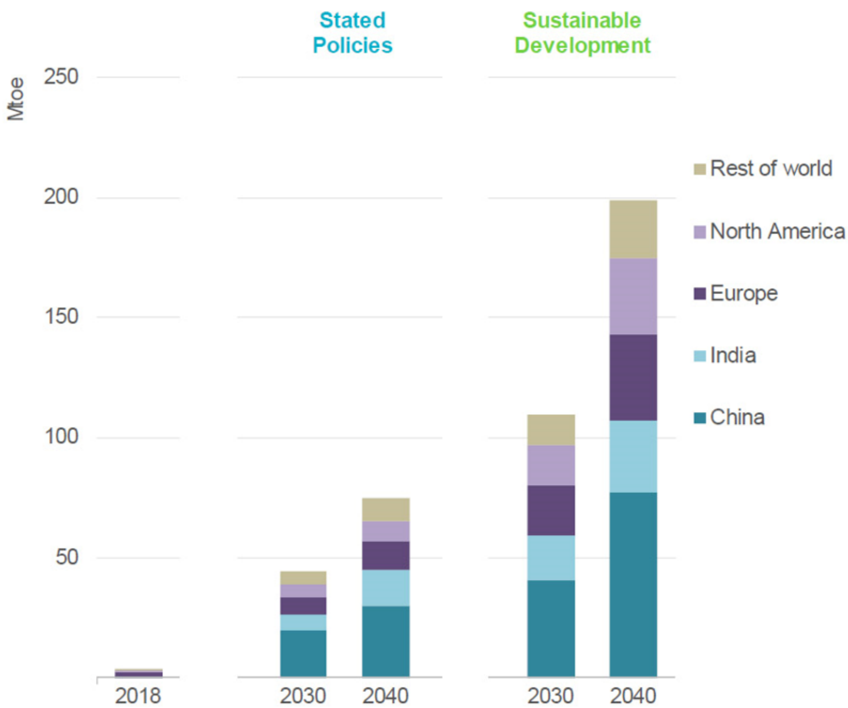


***Fig. 1.8 - Forecast of the biomethane market development in the world until 2040 (IEA, 2018) [16]***

However, Europe remains a region with rapid development of the biomethane industry. EBA analysed the potential of biogas and biomethane production by 2050. The potential volume of biogas and biomethane production calculated for 2030 according to various sources, ranges from 35 to 42 bcm of $CH_4$. By 2050,

[16] Outlook for biogas and biomethane. Prospects for organic growth https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth

Eurogas and the Gas for Climate consortium forecast 95 bcm. The IEA calculates the potential of biomethane production in the EU as 125 bcm, which can be reached by 2040.

Recently, the European Commission has developed the REPowerEU plan, which should increase the sustainability of the energy system throughout the EU based on two pillars - the diversification of gas supplies through greater imports of liquefied natural gas (LNG) and pipeline imports from non-Russian suppliers, and greater volumes of production and imports of biomethane and renewable hydrogen [[17]]. The RePowerEU plan covers urgent actions to mitigate the impact of rising energy prices, diversify the EU's gas supply and accelerate the clean energy transition.

In 2020, 18 bcm of biogas and biomethane were produced in the EU. According to the REPowerEU plan, the European biogas and biomethane sector will supply 35 bcm of biomethane by 2030, supporting the EU in achieving climate goals and energy security (Fig. 1.9).

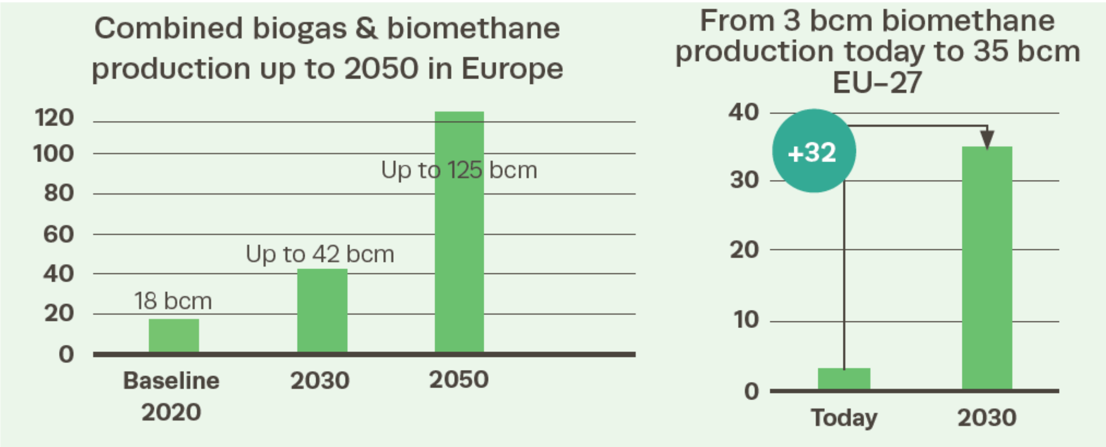


***Fig. 1.9 – Visualization of REPowerEU plan***

The total production of biomethane and biogas should be 42 bcm in 2030 and 125 bcm in 2050. Thus, already in 2030, the share of biomethane should exceed 80% in the total production of biogas and biomethane. Modernization of existing biogas plants to produce more biomethane and expansion of biomethane production capacity itself will provide the EU with a more sustainable energy system.

Capital costs for biomethane production by 2030 may amount to 83 billion euros. In particular, the following facilities will be built:

- 4,000 medium-sized plants (average unit annual capacity – 4 million m$^3$ of $CH_4$, CAPEX per plant – 12 million euros, average cost of biomethane production – 80 euros/MWh)
- 1,000 large plant (average unit annual capacity – 16 million m$^3$, CAPEX – 35 million euros, average cost of biomethane production – 55 euros/ MWh).

## 1.4 Biomethane production technologies

Currently, biomethane is obtained to a greater extent by purification and upgrading 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

[17] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1511

(18%) for biogas upgrading. 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 there is no data on upgrading technology in the EBA database.

If before (2008–2012) chemical scrubber was the most used technology, since 2013 there has been a shift towards membrane separation. 76 plants that started operating in 2020 (47% of the total) are known to use membrane separation.

Additional opportunities for biomethane production include thermal gasification of solid biomass and methanation of synthesis gas, as well as methanation of hydrogen produced by electrolysis (P2G process) using renewable electricity.

Thermal gasification makes it possible to expand the list of raw materials suitable for obtaining biomethane, and to include solid biomass with a high lignin content.

By combining biomethane production with hydrogen, carbon reduction benefits can be obtained, as the $CO_2$ remaining after biogas upgrading can be used in the methanation process. Thus, it is possible to significantly increase the overall efficiency of both processes, as well as the amount of produced biomethane.

Approximately 53% of biomethane in Europe is produced in biogas plants using agricultural raw materials. The second largest source of biomethane production is the organic fraction of municipal solid waste (MSW) (11%);

There is a clear trend in the change of raw materials for the production of biomethane in European countries. The transition from the use of energy crops (maize silage), which were popular in Germany, to agricultural residues, MSW and sewage sludge began in 2016. Almost no new plants have been created to work on energy crops since 2017. In 2019, 60% of raw materials were provided by agricultural residues, 13% by sewage sludge, 10% by MSW, and only 4% by maize silage.

Fig. 1.10 shows that the main source of raw materials for the production of biomethane in recent years is waste and secondary products of agriculture. The second most important source is organic fraction of municipal waste and municipal wastewater. The role of MSW landfills is insignificant (0.8%). Energy crops (maize silage) were actively used in the period from 2008 to 2016, mainly in Germany. Currently, their use for new biogas projects is limited.

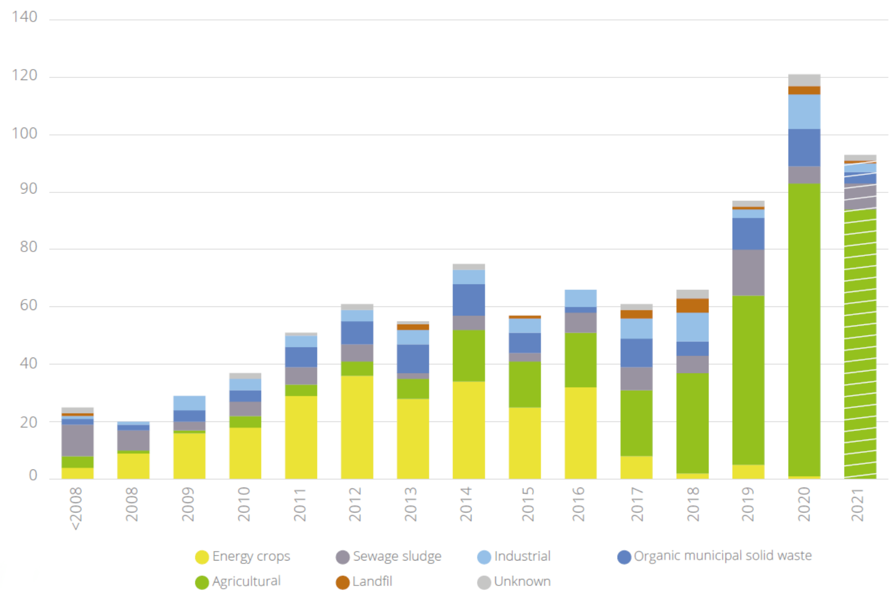


***Fig. 1.10 – Number of new biomethane projects in the EU with a breakdown by types of raw materials (EBA 2021)***

However, despite the gradual abandonment of the use of maize silage, its role remains significant. So, in Germany the share of biogas from maize silage was slightly less than 50% in 2020, and in countries such as Croatia and Serbia - 50-60%.

## 1.5 The use of biomethane

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 upgrading 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 [[18]]. In addition, 10% of European biomethane plants are not connected to the grid, and no information is available on the remaining 23%.

The main market for the production and consumption of biomethane is Germany, where 88% of produced biomethane was used for the combined production of electricity and heat, 5% for heat supply and only about 5% for transport in 2017 [[19]]. 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 (Fig. 1.11).

[18] EBA 2021. "Statistical Report of the European Biogas Association 2021." Brussels, Belgium, November 2021. https://www.europeanbiogas.eu/eba-statistical-report-2021/

[19] Dena, Berlin, July 2018

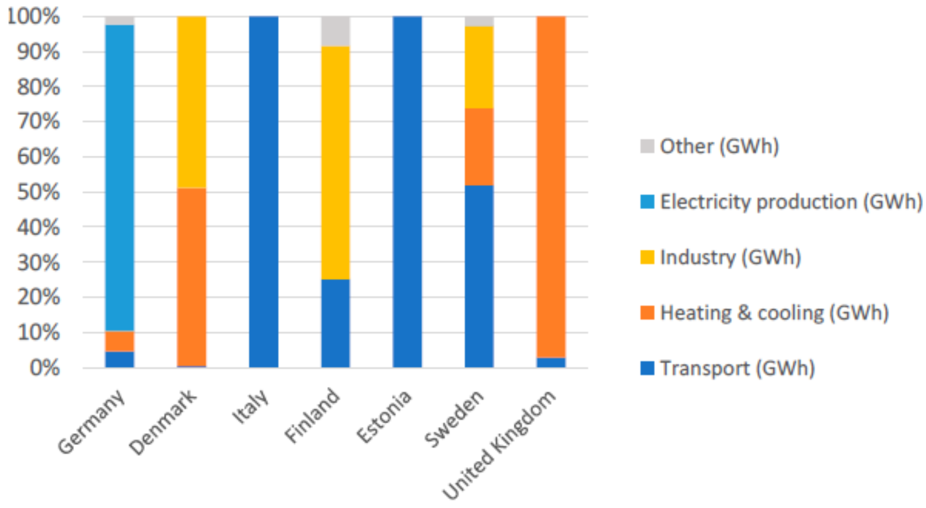


***Fig. 1.11 – Biomethane consumption in the EU by sector (REGATRACE) [[20]]***

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.

In recent years, the share of biomethane use in transport in Germany has practically doubled (Table 1.2) and reached 9%.

***Table 1.2 – Countries with big share of biomethane use in transport (2020) [[21]]***

| Country | BM use in transport, GWh | Share of BM use in transport, % | Number of the filling stations | | | |
|---|---|---|---|---|---|---|
| | | | Bio-CNG | Bio-LNG | CNG | LNG |
| **Sweden** | 1163 | 83 | 265 | 23 | 265 | 25 |
| **Italy** | 2100 | 100 | ? | ? | 1466 | 103 |
| **Germany** | 1000 | 9 | 533 | 15 | 810 | 86 |
| **Finland** | 109 | ~ 100 | 67 | 11 | 67 | 11 |
| **Estonia** | 97 | 100 | 23 | - | 23 | 2 |

Biomethane can be used in all natural gas engines. There are a significant number of modern gas engines for cars, heavy vehicles, ships and trains that can run on biomethane. Most car manufacturers offer vehicles that run on compressed (CNG) or liquefied (LNG) natural gas. There is also the option of converting a car with a gasoline engine to run on gas. An important condition for development is the presence of the necessary infrastructure - a sufficient number of gas filling stations, either CNG or LNG.

[20] REGATRACE. Mapping the state of play of renewable gases in Europe
[21] EBA Statistical Report 2021

# Chapter 2. Support mechanisms for biomethane production and consumption

## 2.1 Support mechanisms adopted in leading European countries

The production of biomethane in the EU has developed actively within last decade. During this period, the cost of biomethane production exceeded the price of natural gas on the market. Therefore, the development of biomethane production was the result of political will and effective mechanisms of financial support and investment subsidies, since biomethane could not compete with natural gas in market conditions. It should be noted that at the current high prices for natural gas, the importance of support mechanisms is decreasing.

Biomethane production in **Germany** was formed with the support of a fixed tariff for electricity produced from biogas and biomethane (0.13-0.24 €/kWh). Back in 2009, producers received a special surcharge to the tariff for biogas upgrading to the quality of natural gas (0.03 €/kWh). In 2014, the surcharge was cancelled, but by this time, 175 biomethane plants were already under operation in the country. After that, due to the reduction of legislative support, the development of the biomethane market in the country slowed down significantly.

**The UK** offers a support scheme developed under the Renewable Heat Incentive (RHI) scheme. The scheme offers a feed-in tariff (FiT) for biomethane from anaerobic digestion when injected into the natural gas network. Biomethane is paid for the amount of energy supplied, the tariff depends on the size of the project and the year of commissioning. The scheme was implemented in 2011, which explains the increase in the number of biomethane plants in the country since that year.

In **Denmark**, there is a premium to the market price of NG, the final biomethane tariff is at least 0.0735 €/kWh. The country considers biomethane as a full-fledged substitute for natural gas. It is planned that in 2025 the production of biomethane and NG in the country will become equal, and in 2035 biomethane will completely replace NG. In addition, Denmark is developing the concept of sustainable energy networks, which combine electricity and gas networks, as well as a district heating system. Biomethane is a renewable energy source that can be stored in gas networks. These features allow to consider it as an important component of the energy system and regulator of solar and wind energy.

The existing system in **France** of subsidizing the price of biomethane supplied to gas networks (0.045 - 0.135 €/kWh) has turned the country into the most successful biomethane market in Europe. The tariff for biomethane in France depends on the size of the project and the type of raw materials for the production of biomethane. France supports the production and delivery of biomethane to gas networks regardless of its further use. It is assumed that in 2023 the production of biomethane in the country will amount to 8 TWh (0.8 bcm) in 2023 already 90 TWh (9.0 bcm) in 2030 or a third of the consumption of NG. Around 7.0 bcm can be provided by fermentation processes, 2.0 bcm by thermal gasification and subsequent methanation of synthesis gas, and about 0.2 bcm by hydrogen generation through electrolysis with subsequent production of methane from hydrogen and carbon dioxide.

**Italy** is also a potential European leader in the biomethane market, where the state encourages the use of compressed and liquefied biomethane as motor fuel in transport by various methods. At the beginning of 2019, 900 applications were submitted in the country for connecting biomethane to gas networks with a total annual capacity of 2.2 bcm. In 2023, the transport sector in Italy is expected to consume 2 bcm of gas, of which 25% will be supplied by bio-CNG.

The rapid growth in Italy is due to a combination of several factors. Already today in Italy there is a developed infrastructure for the use of gas as a motor fuel. More than a million cars and 3,300 buses use methane. More than 1,400 CNG and 100 liquefied natural gas (LNG) gas stations are under operation. The country's national energy strategy envisages the construction of 2,400 CNG and 800 LNG filling stations by 2030.

Consequently, national support schemes include such measures as fixed tariffs for biomethane or electricity produced from biomethane, investment support, quota systems or tax incentive. In addition to financial support, incentive measures regarding licensing and legal aspects are possible to reduce implementation risks (Table 2.1).

***Table 2.1 – National biomethane support scheme in the EU***

| Production site | Consumption site |
|---|---|
| Direct investment support<br>• Grants for plant construction<br>• Interest reduced loan | Feed-in-tariffs, e.q. for<br>• Renewable electricity from CHP<br>• Renewable gas |
| Cost sharing for grid connection | Obligatory quota, e.q. for the consumption of<br>• Renewable fuel<br>• Renewable heat<br>• Renewable electricity |
| Priority (at least nondiscriminatory) access to the public grid | Investment support, e.q. for<br>• CHP system<br>• CNG cars<br>• Bus and vehicle fleets |
| Transparency in terms of technical requirements for gas feed-in | Beneficial tax policy, exemption or refund, e.q. in terms of<br>• Energy tax<br>• Fuel tax<br>• Electricity tax<br>• Income tax |
| Standardization of licensing procedures for plant construction | Revenues from emission trade |

Figure 2.1 summarizes the main national biomethane support schemes in EU countries according to REGATRACE project data.

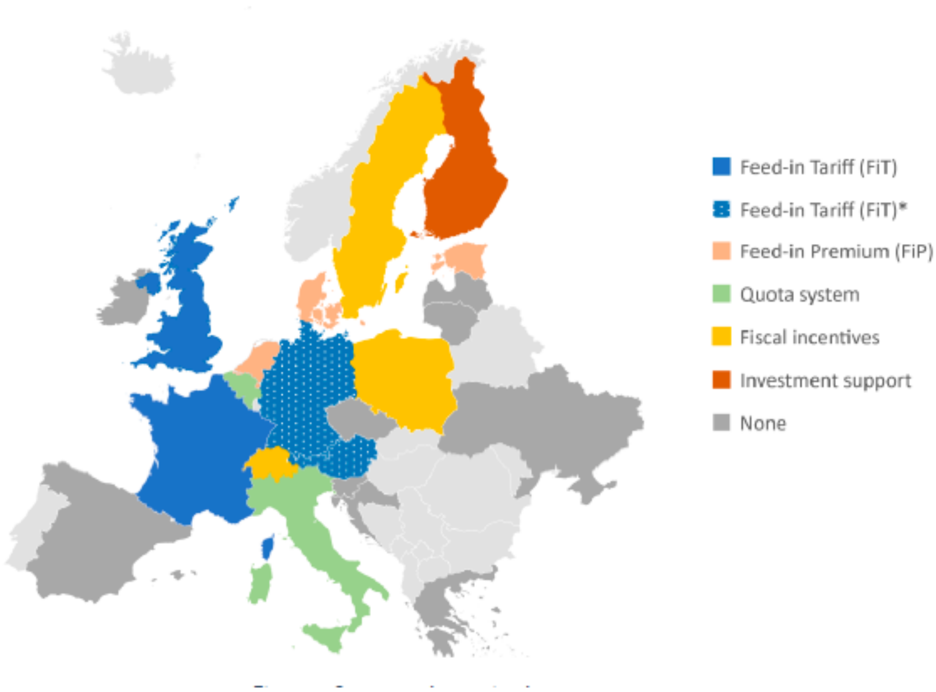


***Fig. 2.1 – National support schemes for the production and use of biomethane i n the EU (REGATRACE). [22]***

## 2.2 Fixed (feed-in) tariff for electricity or biomethane

The fixed (feed-in) tariff (FiT) is the most popular tool for increasing biomethane production, with at least 18 EU countries offering this system. Different support systems use different approaches: FiT on biomethane or electricity produced from biomethane, bonuses to the market price, etc. Each country has its own national support system, for example, Germany had a renewable energy law (EEG) until 2014, which dramatically increased the size of the market. Examples of some countries regarding tariffs for electricity and biomethane are given in the table. 2.2.

[22] REGATRACE. Mapping the state of play of renewable gases in Europe

***Table 2.2 – Examples of FiT for electricity and biomethane in the EU countries***

| Country | Feed-in-tariff for electricity | Feed-in-tariff for biomethane |
|---|---|---|
| Germany (before 2014) | Biogas base tariff plus bonuses for biogas upgrading), BG 0,134 – 0,237 EUR/kWh, BM technology bonus 0,03 EUR/kWh | - |
| Denmark | - | FIP (premium) on top of NG, final price for BM 0,0735 EUR/kWh (0,735 EUR/$Nm^3$) |
| UK | FIT for electricity from BG/BM is paid on top of electricity price: 0.100-0.116 EUR/kWh | FIP on top of NG, biomethane tariff: T1: 0,086 EUR/kWh (0,860 EUR/$Nm^3$), T2: 0.056 EUR/kWh (0,560 EUR/$Nm^3$), T3: 0.039 EUR/kWh (0,390 EUR/$Nm^3$) |
| The Netrherlands | - | The SDE+ scheme. Five categories ranging from 0.483 EUR/$Nm^3$ to 1.035 EUR/$Nm^3$ |
| Austria | Biogas base FIT 0,156 – 0,186 EUR/kWh, technology bonus for biogas upgrading 0,02 EUR/KWh | - |
| France | FIT for biogas only 0,150 – 0,175 EUR/kWh | Landfills - 0,045-0,095 EUR/KWh (0,450-0,950 EUR/$Nm^3$), Agro - 0,085-0,125 EUR/KWh (0,850-1,250 EUR/$Nm^3$), Sewage - 0,065-0,135 EUR/KWh (0,650-1,350 EUR/$Nm^3$) |

## 2.3 Support schemes for the transport sector development

Switzerland, Austria and Sweden grant an exemption from natural gas tax for the use of biomethane as motor fuel. The UK and the Netherlands use quotas based on the energy value of the fuel. Germany is a country that has implemented a control system for reducing GHG emissions on biomethane motor fuel.

The new decree of the Ministry of Italy on the promotion of the use of biomethane and advanced biofuels in transport for the period 2018-2022 (the Biomethane Decree) aims to promote biomethane and advanced biofuels to increase the share of renewable fuels in the transport sector.

The decree introduces a support scheme for biomethane fed into the NG grid for use in the transport sector. It allocates 4.7 billion Euros and covers the maximum amount of 1.1 billion m3/year of biomethane production for the period from 2018 to 2022. This scheme is funded by motor fuel suppliers under their commitment to a mandatory biofuel share (9% biofuels by 2022, including 1.39% biomethane and 0.46% other advanced biofuels). Thus, biomethane occupies 75% in the structure of modern biofuel.

## 2.4 Voluntary market

Voluntary sales of biomethane certificates have been increasing across Europe since 2016. The most significant volumes are traded on the dena-Registry voluntary market (Germany, Switzerland, Denmark, Sweden, Hungary). Another example is the Vertogas trade between the Netherlands and the Scandinavian countries.

# Chapter 3. Potential of biomethane production in Ukraine

## 3.1 Raw materials for biomethane production

The raw material for production of biomethane can include a long list of organic materials. In general, 12 separate categories of raw materials can be distinguished, as shown in the table. 3.1.

***Table 3.1 – Categories of raw materials suitable for biogas/ biomethane production***

| № | Category | Sources | Raw materials (feedstock) |
|---|---|---|---|
| 1 | Livestock manure | - Cattle (dairy) farms<br>- Pig farms<br>- Poultry farms<br>- Other farms | - Dry manure with bedding<br>- Liquid manure<br>- Litter |
| 2 | Harvest residues of agricultural crops | - plant growing enterprises | - grain straw (primarily wheat)<br>- maize stalks and ears<br>- sunflower stalks and baskets<br>- sugar beet residuals |
| 3 | By-products and waste of the food processing industry | - sugar factories<br>- distilleries<br>- breweries<br>- starch and molasses production<br>- flour and grain mills<br>- oil extraction plants<br>- meat processing plants<br>- slaughterhouses<br>- canneries<br>- winemaking enterprises<br>- other production | - beet pulp<br>- molasses<br>- a grain of beer<br>- alcohol bard (grain, post-meal)<br>- fruit juices waste<br>- squeezes and vegetable waste<br>- grape juice waste<br>- oily cake and fudge<br>- sunflower husks<br>- cereal husks<br>- chaff, bran and other grain waste<br>- by-products of animal origin, according to [23], etc. |
| 4 | Bioethanol and biodiesel production waste | - bioethanol plants<br>- biodiesel plants | - alcohol bard<br>- rapeseed meal/cake<br>- glycerine |
| 5 | Energy crops | • plant growing enterprises | • maize silage<br>• sorghum silage<br>• piercing-leaved sylphium<br>• sugar beet<br>• winter rye, others |
| 6 | Phyto-biomass | - natural water bodies<br>- artificial water sources and systems | - higher aquatic vegetation<br>- microalgae |
| 7 | Waste from horticultural and park farms | - communal park<br>- airports<br>- large sports fields with a natural surface | - removed grass from lawns<br>- fallen leaves |
| 8 | Trade and catering waste | - communal and private catering<br>- food markets and shops | - leftovers of ready-made food<br>- substandard food products<br>- food residues and waste<br>- used oil |
| 9 | Municipal solid waste | - sorting stations | • organic fraction of MSW |

[23] Law of Ukraine 287-VIII «About by-products of animal origin, not intended for human consumption»: https://zakon.rada.gov.ua/laws/show/287-19#Text

| № | Category | Sources | Raw materials (feedstock) |
|---|---|---|---|
| | | - mechanic-biological processing plants<br>- garbage cans with separate collection of organic waste | |
| 10 | Municipal wastewater and its sediments | • municipal treatment facilities<br>• local sewage treatment plants of industrial enterprises | • primary sediments of aeration stations<br>• secondary sediments (activated sludge) of aeration stations<br>• fat sludge<br>• concentrated industrial wastewater<br>• |
| 11 | Sequential crops (green fertilisers) | • plant growing enterprises | • vetch<br>• rye<br>• turnip / radish<br>• legumes<br>• clover, others |
| 12 | Vegetation of meadows | • natural meadows that are not used for farming and which are not included in the nature reserve fund | multi-species perennial grasses cut from meadows |

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 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 a guaranty of 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 biomethane production 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. Such types include, for example, manure waste, substandard food products, the organic fraction of solid waste, sewage sludge, grass clippings of artificial lawns, by-products of animal origin that are not suitable for human consumption, etc. (Table 3.1, No. 1, 3, 7 -10). The same list also includes crop residues that are not used for animal feed, for example, grain straw, maize stalks, etc. (Table 3.1, No. 2).

One of the promising types of raw materials for biogas, which does not compete with food and fodder products, are sequential crops grown in the interval between two annual food crops. The use 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 EBA [[25]], more than a quarter of the biomethane production potential can be ensured by using cover crops for this purpose.

[24] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001
[25] EBA 2021. “Statistical Report of the European Biogas Association 2021.” Brussels, Belgium, November 2021.

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 maize silage. Therefore, when producing biomethane in Ukraine for export from maize silage, it should be borne in mind that the contract price for it may be limited.

However, the use of maize 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 maize 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 maize silage for biogas in Ukraine, the following arguments can be mentioned:

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 [[26,27]]. 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 some EU countries, the use of maize silage for biogas is incomparably smaller. So, for example, in Germany as early as 2012, about 1 million hectares were used for growing maize for silage for biogas, which was 8.3% of the total arable land area of 11.57 million hectares [ ]. In 2019, the total use of land resources for the cultivation of raw materials for biogas in Germany was already 1.55 million hectares, and the total for all types of energy crops was 2.67 million hectares [[28]]. According to UABIO, in Ukraine in 2020 maize silage for biogas was grown on an area of 14-20 thousand hectares, which is only 0.4-0.6% of the total arable 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.

[26] https://uk.wikipedia.org/wiki/Список_країн_за_населенням
[27] https://uk.wikipedia.org/wiki/Список_країн_за_використанням_землі
[28] BASISDATEN BIOENERGIE DEUTSCHLAND 2021. FNR: https://mediathek.fnr.de/broschuren/basisdaten-bioenergie.html

## 3.2 The structure of raw materials use for biogas production in Ukraine

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 maize silage. According to UABIO, the total consumption of these types of raw materials is about 97% by fresh weight (Fig. 3.1), and the total share of produced biogas from them is about 92% (Fig. 3.2). The largest volume of biogas is currently produced from sugar beet pulp (39.8%) and maize silage (38.4%). Grain chaff, molasses, fatty sludge and some other types of raw materials are also used in relatively small quantities.

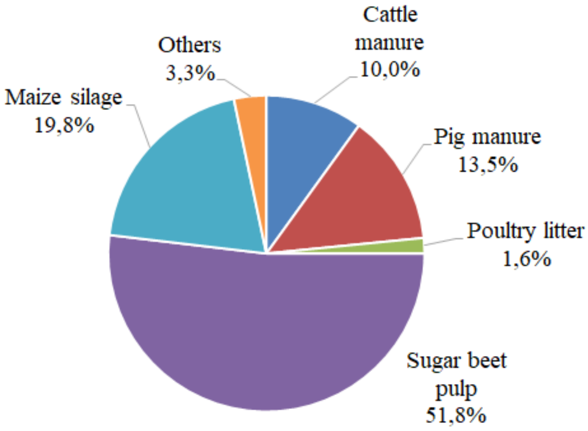


***Fig. 3.1 – The structure of raw materials consumption for biogas production, 2020***

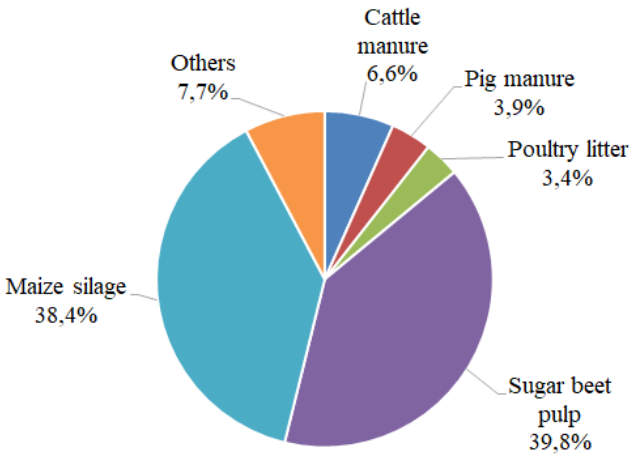


***Fig. 3.2 – The structure of biogas production by types of raw materials, 2020***

Recently, there have been examples of cereal straw and maize stalks use, which is a promising direction. There are also examples of biogas production from wastewater of industrial enterprises (wastewater from the production of chips, yeast, beer, cardboard). Sludge from municipal sewage treatment plants is partially used only at the Bortnitcy WWTP, although biogas production projects are also being developed at a number of other large WWTPs (for example in Kharkiv and Lviv). Currently, there are still no examples of using the organic fraction of MSW for the production of biogas or biomethane.

According to UABIO, the total potential of cattle manure is used by approximately 4%, pig manure by 6%, manure by 1%, sugar beet pulp by 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.

## 3.3 Energy potential of biomethane production

The assessment of the energy potential of biomethane production in Ukraine is based on the analysis of the current 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 municipal economy (2020). The types of raw materials taken into account for 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. 3.3.

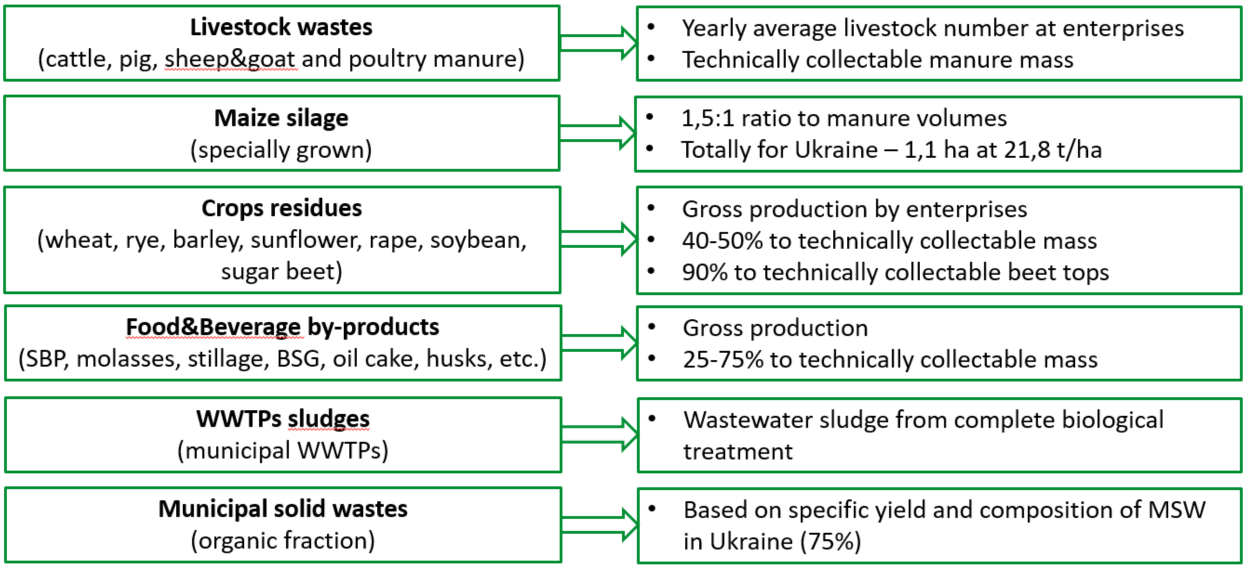


***Fig. 3.3 – Types of raw materials taken into account for the assessment of biomethane production potential***

The production potential of $CH_4$ from the specified types of raw materials is estimated at the level of individual regions and takes into account the temporarily occupied and annexed territories of Ukraine, which unite the parts of Luhansk and Donetsk regions and the Autonomous Republic of Crimea. One can read more about the potential calculation method at [[29]].

The total estimated annual potential of $CH_4$ production is 9.7 bcm, which corresponds to almost 50% of the total volume of NG production in Ukraine (19.5 bcm) and exceeds the volume of NG imports (9.1 bcm) as of 2020 [[30]].

Half of this potential is associated with crop residues, and another third is with growing of maize for silage (Fig. 3.4). The total contribution of all animal manure waste is only 9.2%. All by-products and food industry waste add a total of 6.7%. The organic fraction of MSW and sewage sludge increase the potential by another 6.1%. The share of the potential belonged to the temporarily occupied and annexed territories of Ukraine, as of February 23, 2022, is 4.8%.

Among livestock manure waste, the largest share of the potential, 53.5%, belongs to poultry litter (Fig. 3.5). Among the harvest residues, the largest share is related to wheat straw (34.7%) and maize stems (34.7%) (Fig. 3.6). And finally, among the by-products of the food industry, sugar beet pulp (SBP) (31.3%) and sunflower cake/meal (31.0%) have the greatest potential (Fig. 3.7).

[29] Geletukha, G., Kucheruk, P., Matveev, Y. (2022). Prospects and Potential for Biomethane Production in Ukraine. Ecological Engineering & Environmental Technology, 23(4), 67-80. https://doi.org/10.12912/27197050/149995
[30] Energy balance of Ukraine 2020. State Statistics Service of Ukraine, 2021. http://www.ukrstat.gov.ua/

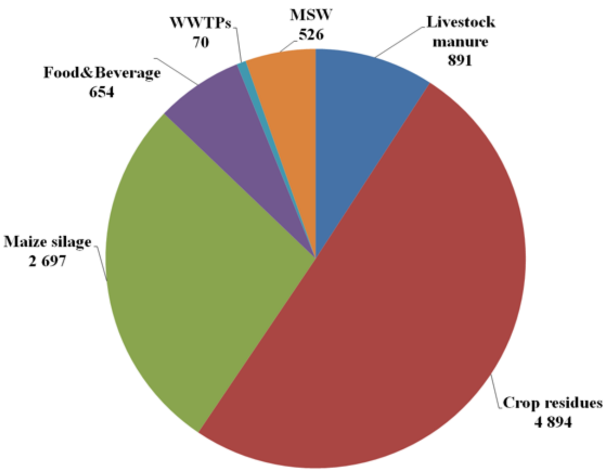


*Fig. 3.4 – General structure of $CH_4$ production potential in Ukraine (2020), mill $m^3$/year*

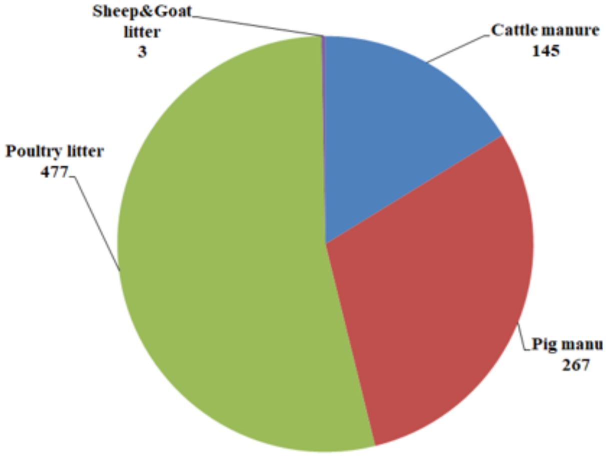


*Fig. 3.5 – Structure of $CH_4$ production potential from manure (2020), mill $m^3$/year*

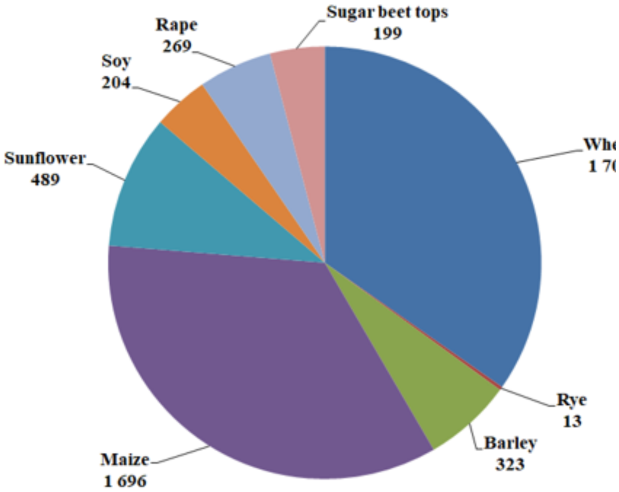


*Fig. 3.6 – Structure of $CH_4$ production potential from agricultural crop residues (2020), mill $m^3$/year*

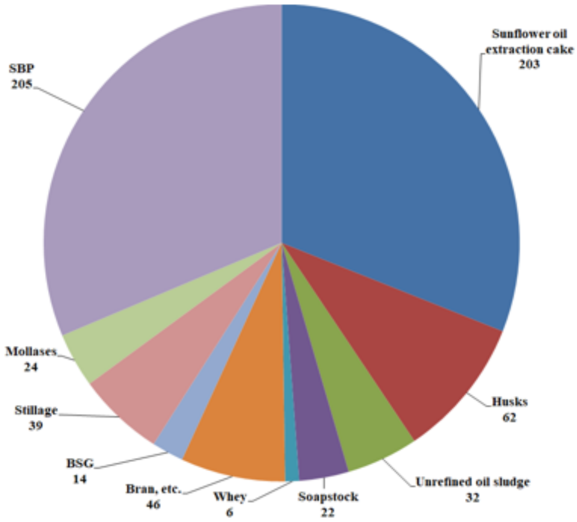


*Fig. 3.7 – Structure of $CH_4$ production potential from by-products of the food processing industry (2020), mill $m^3$/year*

At the regional level, almost half of the $CH_4$ production potential is concentrated in six regions of Ukraine, namely: Vinnytsia, Kyiv, Cherkasy, Poltava, Dnipropetrovsk, and Donetsk regions (Fig. 3.8). The highest potential was assessed in the Vinnytsia region, the lowest in the Zakarpattia region. The potential for $CH_4$ production by region ranges from 38 to 846 million $m^3$/year.

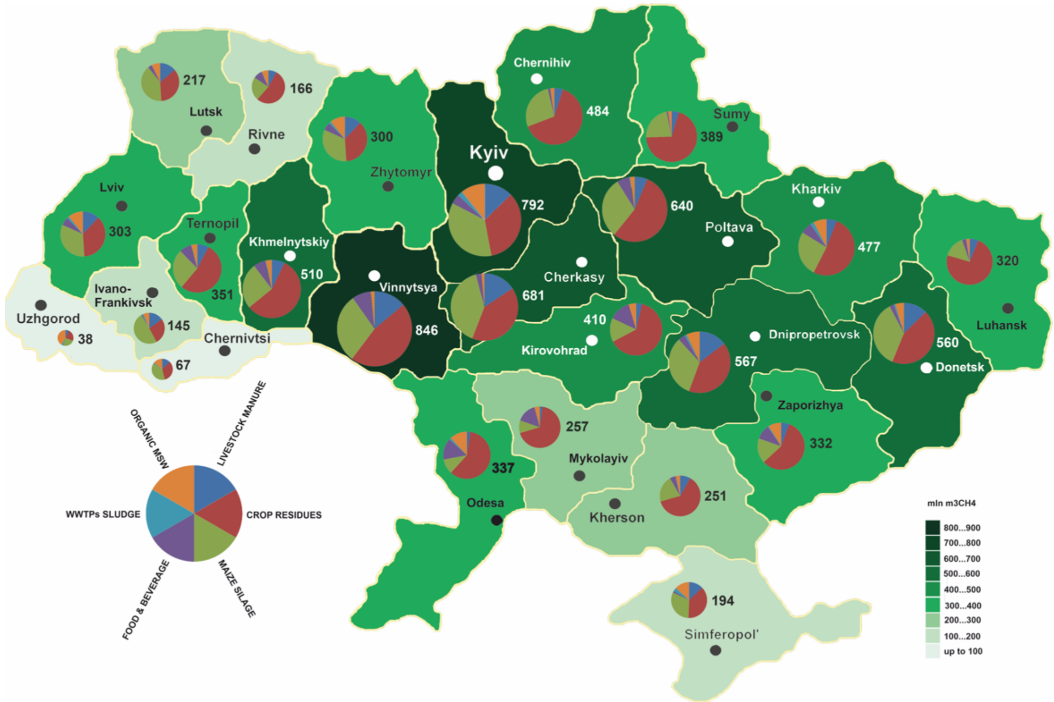


***Fig. 3.8 – Regional distribution of biomethane production potential (2020)***

It should be noted that the estimated potential of CH4 production is not absolute value and can change both to a greater and to a lesser extent. The key factors that can affect the potential are:

- variations in the volume and structure of gross production of plant and animal products;
- changing the area and structure of arable land use for growing food, fodder, technical and energy crops;
- population variation.

The actual production potential of commercial biomethane is smaller by the amount of physical losses of $CH_4$ during purification and upgrading of biogas (up to 3%, depending on the upgrading technology) and by the amount of energy consumption of biogas for the biomethane plant's own needs (as a rule, up to 15-20%, if not other energy sources are used).

According to the forecast of UABIO, the total potential of biomethane production in 2050, under the conditions of growth of crop yields, increase of gross production of products, as well as expansion of the types and volumes of raw materials, by-products and waste used, may increase at least 1.5 times compared to 2020 and reach about 15 bcm/year.

The roadmap for the development of bioenergy in Ukraine until 2050 envisages the introduction and growth of biogas and biomethane production. According to UABIO estimates, the actual production of biomethane in Ukraine may reach 1 bcm in 2030 and 4.5 bcm in 2050 [[31]].

[31] Georgii Geletukha, Tetiana Zheliezna, Semen Drahniev, Olha Haidai. Ten actions of Ukraine to reject Russian natural gas. Position Paper UABIO №28. – 2022. https://uabio.org/materials/12834/

# Chapter 4. Biomethane projects concepts

## 4.1 Project concepts

There are two basic concepts of biomethane production from biogas. The first concept envisages the construction of a new plant for the production of biomethane "from scratch", including a biogas plant and a biogas upgrading facility. The second concept involves the full or partial modernization of existing biogas plants from the production of electricity and/or thermal energy to the production of biomethane, with the installing of biogas upgrading plant and, if necessary, the retrofitting of the biogas plant. Table 4.1 presents a comparison of the advantages and disadvantages of these two concepts.

***Table 4.1 – Advantages and disadvantages of two project concepts***

| | Concept 1 | Concept 2 |
|---|---|---|
| Advantages | • flexibility regarding the choice of the plant construction site depending on the availability of raw materials and the possibility of grid connection or its alternative consumption<br>• the economic model can take into account in advance the consumption potential of commercial biomethane and the acceptable production cost, depending on the scale of the project<br>• the possibility of choosing the optimal combination of the raw material concept and appropriate technological solutions | • significantly lower investment costs<br>• use of already developed logistics and raw material chains<br>• predictability of composition and volume of biogas<br>• shorter period of time until the first volumes of biomethane are produced |
| Disadvantages | • significantly larger investments in the project<br>• the need to find/create sustainable raw material supply chains | • partial or significant wear of the main and axillary equipment of the biogas plant<br>• limitation in choosing a connection point to the gas grid with the necessary technical parameters<br>• possible significant investment costs for biomethane logistics |

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 about 125 million $m^3$ $CH_4$/year [[32]], as well as constant problems with payments under the current "green" tariff in Ukraine, concept 2 also suitable. In order to assess the expediency of switching to biomethane production, existing operators of biogas plants need to find answers to at least the following questions [[33]]:

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

[32] "Statistical Report of the European Biogas Association 2021." Brussels, Belgium, November 2021.
[33] Attila Kovacs, Mieke Decorte, et al. (2022) Guidance for feasibility analysis covering biomethane investment projects. REGATRACE project. Task D6.4. (to be published by the end of 2022)

- is there a possibility to increase the biogas production capacity? 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 land to accommodate a biogas upgrading station and additional biogas production facilities? Space limitations can affect the choice of biogas enrichment technology.
- how much of the power generation equipment (CHP) will remain in operation to provide electricity to both the biogas plant and the biogas upgrading plant?
- what are the technical conditions for connection to the natural gas grid on site (pressure, minimum consumption, etc.)?

## 4.2 Raw materials (feedstock) concepts

The issue of providing raw materials is key for any biogas project. Realization of the estimated biomethane production potential in Ukraine will also require special attention in the matter of providing individual projects with sufficient amounts of raw materials. Such possibilities are limited, on the one hand, by the available structure and concentration of raw materials, and on the other hand, by the available technical possibilities of supplying biomethane to the NG grid or alternative use in the area of the potential construction of a biomethane plant (see chapter 5 for details). Economic expediency determines the need for the construction of larger-scale projects, which can aggravate the problem of providing the project with a sufficient amount of raw materials.

The total volume of raw materials in an economically feasible delivery radius determines the potential capacity of the biomethane plant. At the same time, the capacity of the biomethane project is one of the key factors determining its investment attractiveness. It is obvious that the lower threshold of investment attractiveness in terms of scale will also be determined by the cost of raw materials, which can reach from a few percent to 50% or more (see chapter 6 for more details) in the cost of biomethane.

From the point of view of ensuring the lowest cost of biomethane, the project should focus primarily on cheap types of raw materials, for example, manure, litter, sugar beet pulp. This also determines the connection of the project to the source of raw materials. Currently, in Ukraine, almost all biogas plants in the agricultural sector are built on the basis of livestock farms or sugar factories.

The analysis of the available capacities of livestock breeding and food processing enterprises in Ukraine shows that the potential number of large biomethane projects with a capacity of 1000 $m^3$ $CH_4$/h or 8.5 million $m^3$/year, focused only on the raw materials of an individual enterprise, is limited. According to the estimates of the SEC "Biomass" [[34]], the production of such volume of biomethane based only on the company's own raw materials could be organized at 12 livestock enterprises out of 4,611 operating in 2020 [[35]], 15 sugar factories out of 30-31 operating in the seasons of 2019/ 2020 and 2020/2021 [[36,37]], 15 oil extraction plants (based on cake/meal and sunflower husk), one brewery (based on beer grain). It is obvious that the list of potential objects for the implementation of biomethane projects needs to be

[34] Biomethane zoning and assessment of the possibility and conditions for connecting of biomethane producers to the gas transmission and distribution systems of Ukraine: https://saf.org.ua/en/library/1548/
[35] Livestock of Ukraine, 2019. Statistical mix. State Statistics Service, 2020.
[36] https://agronews.ua/news/v-ukraini-nazvano-kil-kist-pratsiuiuchykh-tsukrovykh-zavodiv/
[37] http://ukrsugar.com/uk/post/pusk-cukrovih-zavodiv-20202021-mr-onovleno

expanded by the search for additional types and volumes of raw materials, as well as smaller-scale projects.

To implement plans for biomethane production in Ukraine at the level of 1.0 bcm/year in 2030, it is necessary to build 230 biomethane plants with an average capacity of 500 $m^3$/h of biomethane (4.25 million $m^3$/year of biomethane or the equivalent of a biogas station with a CHP capacity of 2.4 $MW_{el}$) or 115 projects with an average capacity of 1000 $m^3$/h of biomethane. This will mean the construction of approximately 30 or 15 plants per year, respectively, over 12 years. Reducing the average scale of projects will require an even greater number of them. It is worth noting that over the past 12 years, only 22 biogas plants have been built and put into operation in the Ukrainian agricultural sector.

Wide use of plant raw materials, such as maize silage, crop residues and sequential crops, is seen by us as a key direction in the development of biomethane projects. The involvement of such types of raw materials is justified both from a technological point of view (it balances nitrogen-saturated manure waste) and from the point of view of the possibility of increasing the number of large projects. Fairly even distribution of arable land on the territory of Ukraine, on which such types of raw materials can be collected or grown, will allow significant expanding the raw material and productive potential of a separate biomethane project.

Logistic solutions for the organization of biomethane production can be seen as 3 basic options, as shown in Fig. 4.1.

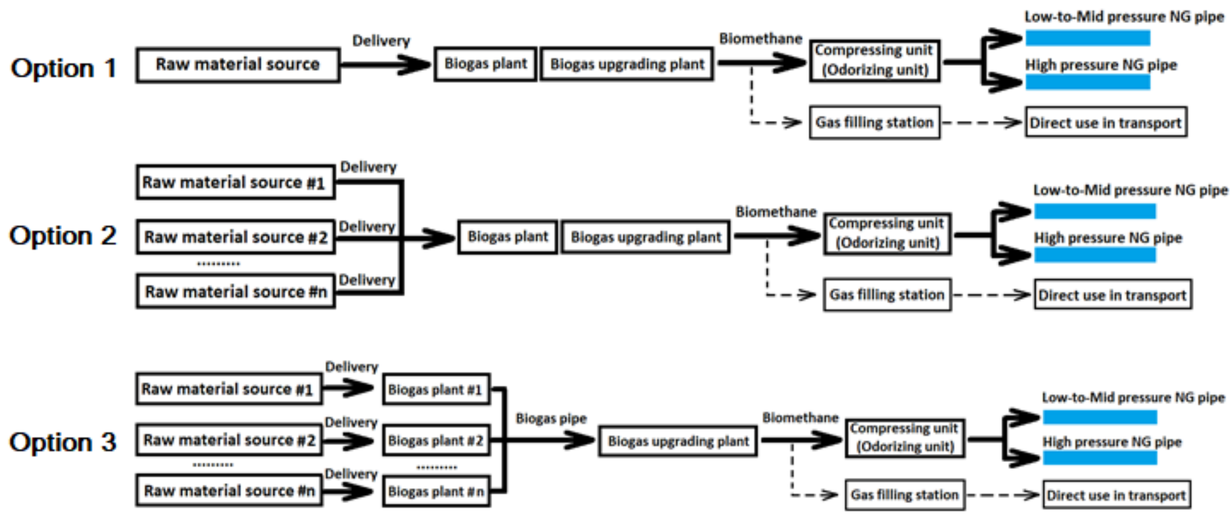


***Fig. 4.1 – Principal schemes for the organization of production and consumption of biomethane***

The first option involves the production of biomethane using the raw materials of one enterprise (for example, a sugar factory). The feasibility of implementing such a scheme is limited to fairly large enterprises and the technological suitability of raw materials for mono-fermentation.

The second option is more flexible and involves the supply of raw materials for biogas production from various sources. The base location for the construction of biogas plant can be the most suitable object, both from the point of view of raw material logistics and further biomethane logistics. For example, the basic object can be a pig farm, where liquid manure is produced, the transportation of which over considerable distances will be economically impractical. The addition of different types of raw materials also allows to optimize the feedstock composition most suitable for efficient biogas production.

The third option involves the supply of raw biogas from separately located biogas plants within certain limited radius to a centralized biogas upgrading facility. Such scheme can be used, for example, when it is expedient to locally process raw materials into biogas at separately located production facilities of the company (separate poultry brigades, or pig farms).

## 4.3 Product concepts

The concept of production and use of biomethane and its derivative products is usually determined by economic feasibility. The determining factors are, first of all, the market needs of individual countries or regions for one or another type of product, market prices for individual technology products, as well as existing financial incentive schemes.

There are no universal concepts that can quickly respond to market changes. From the point of view of economic efficiency, the most appropriate is the production of certain types of products by biomethane plant that works evenly throughout the year at full capacity. Any change in the product concept of the biomethane plant will require both time and significant financial resources.

Currently, there are 3 main options of energy and material use of produced biomethane, namely:

- commercial biomethane as a substitute for natural gas in NG grid;
- compressed biomethane (bio CNG) as motor fuel;
- liquefied biomethane (bio LNG) as motor fuel.

There are different requirements for the quality and physical parameters of each type of biomethane (see chapter 5 for more details), which will require the installation of different types of equipment.

At the exit from the biogas upgrading facility biomethane has a certain pressure depending on the upgrading technology. The magnitude of this pressure, the distance from the station to the point of connection to the NG grid, as well as the pressure in the grid, will determine the possible need for the installation of additional pressure station.

In any case, the production of bio CNG will require the construction of a 200-230 bar pressure station. Liquefaction of biomethane to bio LNG, in addition to compression, will require the construction of a powerful refrigeration plant.

Derivative products of biomethane production technology can also be:

- raw digestate and its fractions after mechanical separation as a soil improver;
- enriched digestate and its derivative products as organic fertilizer or soil improver;
- food grade carbon dioxide;
- carbon dioxide for industrial use (except food industry).

At the current (2022) level of commercial prices for natural gas for industrial enterprises and motor fuels, it can be predicted that all 3 options of biomethane application can be attractive for investment, at least for large projects with relatively cheap raw materials. Given the simultaneous rise in prices and the shortage of certain types of mineral fertilizers, the commercialization of digestate-based products also looks promising. Commercialization of carbon dioxide as a product for various industries, taking into account its renewable component, can also be considered as a reasonable option.

Currently, it is possible to consider 4 main models of sale of commercial biomethane, namely:

- Implementation on the domestic gas market of Ukraine under direct contracts;
- Implementation as motor fuel on the domestic market;
- Virtual export to the EU market with guarantees of origin (use of GTS/GRS and biomethane register);
- Physical export with or without the use of GTS/GRS (for example, liquefied biomethane).

It can be seen that one possible model is to exchange guarantees of origin with European traders either directly or through a virtual export system based on guarantees of origin. For the possibility of virtual export in Ukraine, it is necessary to implement a register of biomethane, synchronized and harmonized with the register of recipient countries. This will make it possible to offset the physical and virtual volume of exported biomethane. At the same time, it is assumed that the physical molecules of biomethane will enter the Ukrainian gas distribution networks, and the equivalent physical volume of natural gas will be pumped by transit to the conditional selection point in the recipient country.

This model envisages the possibility of obtaining, in addition to the current price for natural gas, an allowance/premium for biomethane renewables. Given the lack of any financial support mechanisms for such projects in Ukraine, this makes such a scheme attractive for investment. At the same time, it should be borne in mind that obtaining the maximum possible amount of this premium will require compliance with the EU RED II directive, i.e. preferential use of waste and less use of maize silage.

# Chapters 5. Potential markets for biomethane consumption

## 5.1 Market preconditions for biomethane production and consumption in Ukraine

Biomethane can be considered as a future of biogas, which has already arrived, at least in the EU. With the adoption of the Law of Ukraine 1820-IX [38], a practical opportunity for the development of the biomethane market was opened. There is every reason to expect the appearance of the first volumes of produced biomethane in Ukraine in the near future. It is already known about the first biomethane project [39] of the Gals-Agro company, which should be launched by the end of 2022. For this, there are at least the following market prerequisites, both on the demand side and on the supply side:

- The need to diversify energy supply sources and strengthen the energy independence of Ukraine's economy;
- Political expediency of substituting natural gas consumption from the russian federation;
- The need to maintain the functions of the Ukrainian Gas Transportation System (GTS) to provide the population and industry with sufficient volumes of NG in the event of a reduction or complete stoppage of its transit through the territory of Ukraine;
- Contribution to Ukraine's obligations to reduce greenhouse gas emissions under the Paris Climate Agreement of 2015;
- Further integration with the EU energy market, and, accordingly, the commitment to have a certain share of energy from renewable sources;
- Participation in the EU market for trade in renewable gases, which provides an opportunity to obtain additional financial motivation;
- The economic feasibility of replacing fossil energy resources with biomethane when the price of natural gas is more than 600-700 euros/1000 $m^3$;
- The presence of a developed GTS with the possibility of NG accumulation in underground storage facilities (USF);
- The presence of a significant fleet of vehicles (agricultural, communal), which can be transferred to the consumption of compressed biomethane;
- Availability of own fleet and ports with a significant flow of goods, which are potential consumers of liquefied biomethane.

Ukraine is a country dependent on the import of all types of fuels, albeit to varying degrees. Thus, in 2018, the share of motor fuel imports in the total supply ranged from 77% (liquefied petroleum gas - LPG) to 86% (gasoline and diesel). Dependence on the import of natural gas was 32%, and on coal - 20% (Fig. 5.1).

[38] Law of Ukraine 1820-IX dated 21.10.2021 "On Amendments to Certain Laws of Ukraine Regarding the Development of Biomethane Production": https://zakon.rada.gov.ua/laws/show/1820-20#Text

[39] https://ukragroconsult.com/news/agroholdyng-gals-agro-stane-pershym-postachalnykom-biometanu-do-gazorozpodilnyh-merezh/

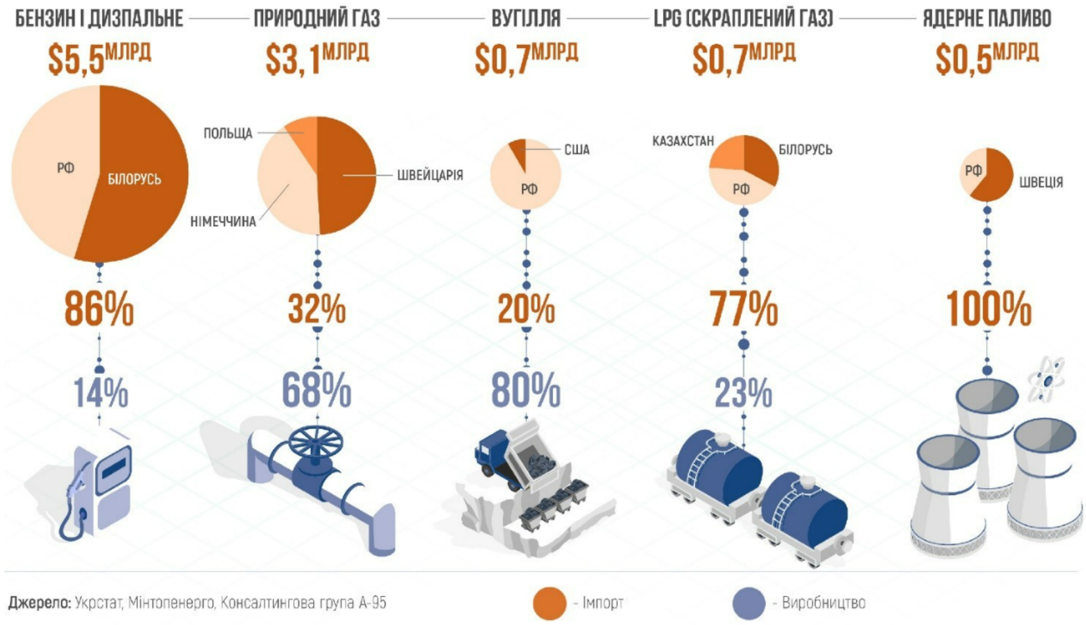


*Fig. 5.1 – Dependence of Ukraine on fuel imports [40]*

Biomethane can be used for substitution both NG and almost all types of motor fuels - compressed natural gas (CNG), liquefied natural gas (LNG), diesel, gasoline, and LPG. Biogas/biomethane can also be a raw material for the production of renewable methanol, which is needed for the production of biodiesel.

Until 2014, NG was imported mainly from the russian federation, then from EU countries (Slovakia, Hungary, Poland). It is obvious that such imports from the EU were mainly re-exports of NG originating from the russian rederation. However, with the beginning of the russian federation's war against Ukraine, and the EU countries' radical revision of energy policy and their own dependence on fossil fuels from the russian federation, the possibility of such re-exports for Ukraine in the future looks debatable. Also taking into account the high risk of a complete cessation of NG transit from the russian federation through the territory of Ukraine by the end of 2022 [41], the issue of replacing the volumes of imported GHG becomes critical. The issue of replacing motor fuels, which until 2022 were supplied mainly from unfriendly countries, is also relevant.

The estimated biomethane production potential of about 10 bcm/year is sufficient to fully cover the pre-war needs in imported NG and partially the needs in motor fuels, depending on priorities and economic feasibility. However, the realization of this potential will require a considerable period of time, and therefore the biomethane market in Ukraine should start as soon as possible.

Biomethane is a universal gaseous energy carrier that can be used in various applications. The indisputable advantage of biomethane is its renewability and sustainability (when using sustainable types of raw materials). The main possible applications of biomethane and the corresponding potential markets are shown below.

40 Ukrainian Institute for Future (2018). Ukraine will be an energy-independent country in 5 years. In 10 years - a supplier of energy to Europe.- https://strategy.uifuture.org/ukraina-cherez-5-rokiv-energonezalezhna-kraina.html
41 https://news.lviv-company.in.ua/gazprom-zmenshiv-obsyagi-tranzitu-cherez-ukra%D1%97nu-rizik-obstriliv-gts-zrostaye-makogon.html

- **Replacement of NG with biomethane.** Biomethane can be used for any purpose as a substitute for NG. In this way, it is possible to replace imported natural gas and liquid petroleum products, as well as fulfil Ukraine's obligations to reduce GHG emissions within the framework of the Paris Agreement.
- **Use of biomethane as motor fuel for road transport, agriculture, aviation and marine transport.** This option allows you to replace fossil motor fuel like gasoline, diesel, aviation fuel, CNG, LNG, and LPG. This is an excellent opportunity for agricultural producers to obtain fuel from waste and secondary products of their own production. The use of biomethane as a fuel for public transport can significantly reduce air pollution in large cities. The use of biomethane in passenger cars is also possible, it is popular in some, including developed, countries (European example - Italy).
- **Biomethane export to the EU using the national register of biomethane production and consumption.** Using the capabilities of Ukraine's gas transportation system, which is connected to the European NG system, through the virtual export mechanism can increase the economic attractiveness of biomethane production in Ukraine.
- **Production of electricity and heat from biomethane using the NG grid.** This option makes it possible to produce electricity and thermal energy in the immediate vicinity of the consumer and, thus, to increase the efficiency of fuel use due to the efficient use of thermal energy, at least in urban district heating systems. Currently, biogas in Ukraine is used with an efficiency that does not exceed 50%.
- **Storage of biomethane in the NG system for electricity production at peak load.** This option allows you to use biomethane in periods of maximum load on the power system and thereby reduce the need for regulation of electric power, which in Ukraine is mainly provided by coal-fired power plants. The use of biomethane for this purpose can largely compensate for the limited possibilities of regulation of rapidly developing renewable energy sources – solar PV and wind energy.
- **Biomethane as a renewable feedstock for the chemical and other industries.** The consumption of NG in the chemical industry is related to the production of derivative products, such as nitrogen mineral fertilizers, methanol, ammonia, etc. Possible export restrictions on products using fossil fuels, in particular due to the carbon border adjustment mechanism (CBAM), in the long run may stimulate domestic producers to switch to the consumption of renewable raw materials, which in the chemical industry can replace NG with biomethane.

## 5.2 Biomethane on the NG market. Regulatory requirements for GTS/GDS delivery

The producer of biomethane, who is going to supply biomethane to GTS or GDS, becomes a subject of the NG market of Ukraine and will be considered a gas production entity. Therefore, its activities will be regulated, in particular, by the current Law on the Natural Gas Market [[42]], the GTS Code [[43]], the GDS Code [[44]] and other relevant by-laws and regulatory documents.

[42] Law of Ukraine 329-VIII dated 01.05.2022 p. «On natural gas market»: https://zakon.rada.gov.ua/laws/show/329-19#Text

[43] Resolution of the NCSRECS No. 2493 "On Approval of the Code of the Gas Transport System of Ukraine" dated September 30, 2015: https://zakon.rada.gov.ua/laws/show/z1378-15#Text

[44] Resolution of the NCSRECS No. 2494 "On Approval of the Code of Gas Distribution Systems of Ukraine" dated September 30, 2015: https://zakon.rada.gov.ua/laws/show/z1379-15#Text

It is possible to supply biomethane to GTS or GDS if its physical and chemical characteristics meet the requirements for natural gas specified in the Gas Station or Gas Station Code (Table 5.1).

### *Table 5.1 – Requirements for NG content according GTS and GDS Codes*

| Parameter | Value |
|---|---|
| Methane content ($C_1$), mol. % | ≥ 90 |
| Ethane content ($C_2$), mol. % | ≤ 7 |
| Propane content ($C_3$), mol. % | ≤ 3 |
| Butane content ($C_4$), mol. % | ≤ 2 |
| Content of pentane and heavier hydrocarbons ($C_5$ +), mol. % | ≤ 1 |
| Nitrogen content ($N_2$), mol. % | ≤ 5 |
| Carbon content ($CO_2$), mol. % | ≤ 2 |
| Oxygen content ($O_2$) [45], mol. % | ≤ 0,2 [46] (1,0) [47] |
| High calorific value (25 °C/20 °C) | ≥ 36,20 MJ/m³ (10,06kWh/m³) |
| | ≤ 38,30 MJ/m³ (10,64 kWh/m³) |
| High calorific value (25 °C/0 °C) | ≥ 38,85 MJ/m³ (10,80 kWh/m³) |
| | ≤ 41,10 MJ/m³ (11,42 kWh/m³) |
| Low calorific value (25 °C/20 °C) | ≥ 32,66 MJ/m³ (9,07 kWh/m³) |
| | ≤ 34,54 MJ/m³ (9,59 kWh/m³) |
| Dew point temperature by humidity °C at an absolute gas pressure of 3.92 MPa | ≤ -8 |
| The temperature of the dew point of hydrocarbons at a gas temperature not lower than 0 °C | ≤ 0°C |
| The content of mechanical impurities: | no present |
| Hydrogen sulphide content, g/m³ | ≤ 0,006 |
| Mercaptan sulphur content, g/m³ | ≤ 0,02 |

After the approval on August 2, 2022 by the Resolution of the NCSRECS, of amendments to the Code of GTS and GDS regarding requirements for the content of $O_2$ in NG supplied to GDS at a level of no more than 1%, it can be expected that biomethane obtained in the process of biogas upgrading using various technologies will meet the requirements for GDS delivery. At the same time, it should be borne in mind that various upgrading technologies as a rule are not designed to effectively reduce $O_2$ in biogas, and therefore its content in biomethane will be almost at the same level as in raw biogas. Therefore, the process of biogas production and its further delivery to upgrading facility must ensure an acceptable level of $O_2$ concentration. It is also necessary to take into account that when $CO_2$ is removed, the volume of biomethane will be almost half as much, and therefore the concentration of $O_2$, which will not be removed by the upgrading facility, may accordingly increase to twice the value in raw biogas.

[45] According to Resolution of the NCSRECS `No. 827 of August 2, 2022 "On Amending the Code of the Gas Transportation System and the Code of Gas Distribution Systems":https://www.nerc.gov.ua/acts/pro-vnesennya-zmin-do-kodeksu-gazotransportnoyi-sistemi-ta-kodeksu-gazorozpodilnih-sistem
[46] When supplying biomethane to GTS
[47] When supplying biomethane to GDS

Taking into account the requirement for the content of $CO_2$ in NG at the level of no more than 2% by volume, the content of $CH_4$ in biomethane should not be less than 97-98%. According to one of the water scrubber technologies, the manufacturer guarantees a $CO_2$ content in biomethane of no more than 2.0%. But according to one of the membrane separation technologies, the manufacturer guarantees $CO_2$ content of no more than 2.5%. Compliance with the quality of biomethane according to this indicator will need to be confirmed in each individual project in agreement with the relevant operator of GDS. For example, in the technical conditions of connection to GDS offered by one of the regional gas companies, the $CO_2$ content is not more than 2.5%.

The rate of hydrogen sulphide content of no more than 0.006 g/$m^3$ (equivalent to 4.4 ppm) is also quite achievable for biomethane. For example, according to one of the water scrubber technologies, the content of hydrogen sulphide in biomethane is declared at a level of no more than 0.1 ppm, and according to one of the membrane purification technologies - no more than 0.005 g/$m^3$.

Thus, biomethane obtained using modern biogas upgrading technologies can fully meet the requirements for its supply to NG system in Ukraine, in particular, to GDS.

Delivery of biomethane to GTS Ukraine will require in most cases further purification of biomethane from oxygen, and accordingly an increase in capital and operating costs for purification and compression of biomethane to 50-55 bar.

## 5.3 Ability of GTS and GDS of Ukraine for biomethane receiving

In Ukraine, there is a fairly extensive system of NG supply, which includes a gas transportation system (GTS), a gas distribution system (GRS), underground storage facilities (USF), gas production enterprises and all the necessary infrastructure (compressor stations, gas distribution stations, etc. ). According to the data of the Operator of the GTS [[48]], the total length of gas pipelines is 33,400 km [[49]], of which: 21,100 of main gas pipelines, 12,100 km of branch gas pipelines and 200 of distribution gas pipelines (Fig. 5.2). The total number of gas distribution stations 1,390 units.

From a technical point of view, this whole system is fully compatible for receiving and transporting biomethane. From the point of view of total throughput, the gas network in Ukraine is able to receive at least the volume of biomethane equivalent to the volume of imported natural gas used for domestic consumption.

[48] Development plan of LLC Operator GTS of Ukraine 2020 – 2029

[49] Without taking into account the temporarily occupied Autonomous Republic of Crimea and parts of Donetsk and Luhansk regions as of February 23, 2022.

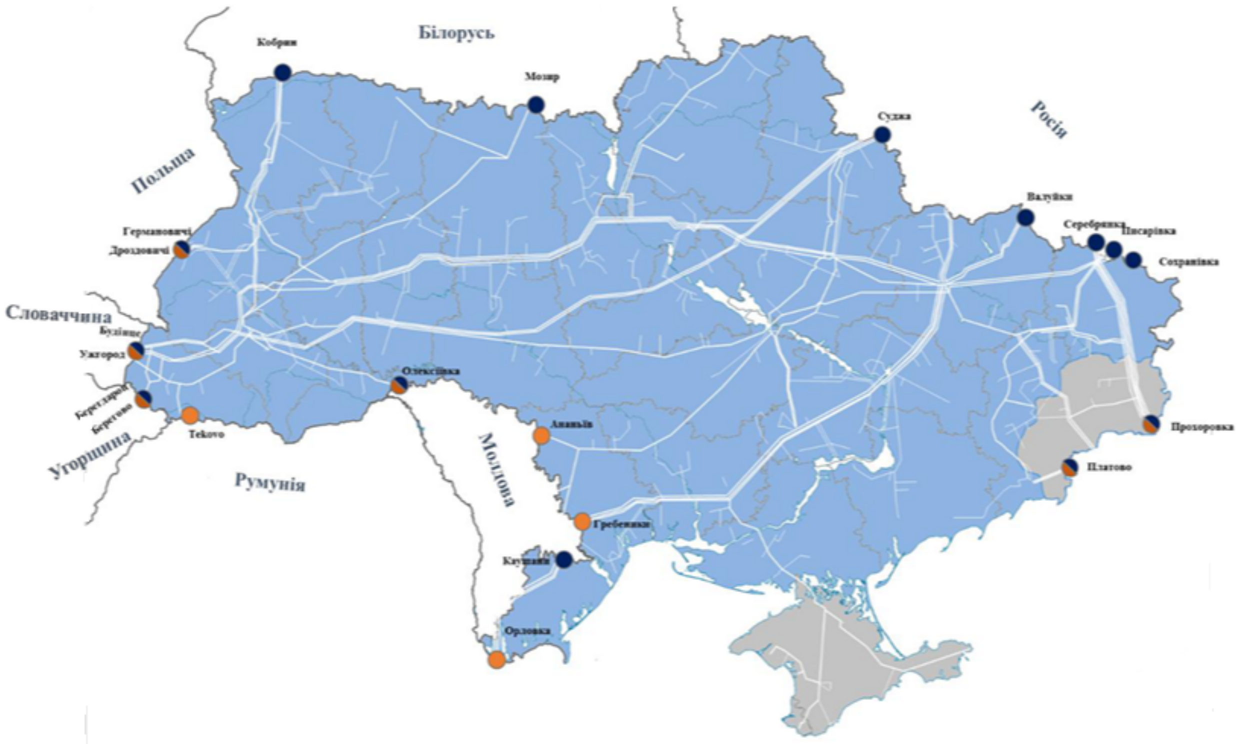


***Fig. 5.2 – Map of the gas transportation system of Ukraine [50]***

According to the data of the Operator of the GTS of Ukraine, in 2021 the consumption of NG (without taking into account technological consumption of GTS and GDS operators, as well as the share of supply within the grid of gas producers) amounted to 27.306 bcm, in 2020 - 28.946 bcm [51]. More than 80% of this volume of NGs (22.609 bcm in 2021) is distributed to consumers through GDS (under the management of the GDS Operator), the rest (3.74 bcm) is delivered to consumers directly from main gas pipelines.

Ukraine's own NG production amounts to 20.0 - 21.5 bcm per year. The volume of NG imports in recent years was 9-10 bcm/year. This is actually the volume that is entirely possible to replace only with biomethane, not taking into account other possibilities of replacing NG with biomass in boiler houses and TPP/CHP, as well as energy efficiency measures. It can be stated that the potential of replacing imported NG is comparable to the estimated by UABIO potential of biomethane production in Ukraine (9.7 bcm/year), which means that it can be expected that projects for the production of biomethane will have long-term prospects for joining and supplying it to Ukraine's GTS/GDS.

Analysis of the regional distribution shows that in the vast majority of regions of Ukraine, the volumes of NG consumption significantly exceed the potential of biomethane production (Fig. 5.3). Therefore, it should be expected that gas grid will be able to physically receive almost the entire volume of biomethane within the limits of its production potential, estimated by UABIO for 2020. A more detailed analysis of the technical potential of NG substitution with biomethane in Ukrainian NG system can be done on the basis of complete data of GTS and GDS operators regarding the modes of NG input and output over time during the year.

[50] Operator GTS of Ukraine

[51] https://finbalance.com.ua/news/minenerho-spozhivannya-hazu-v-ukrani-v-2021-rotsi-skorotilosya-na-94---do-28-mlrd-kubiv

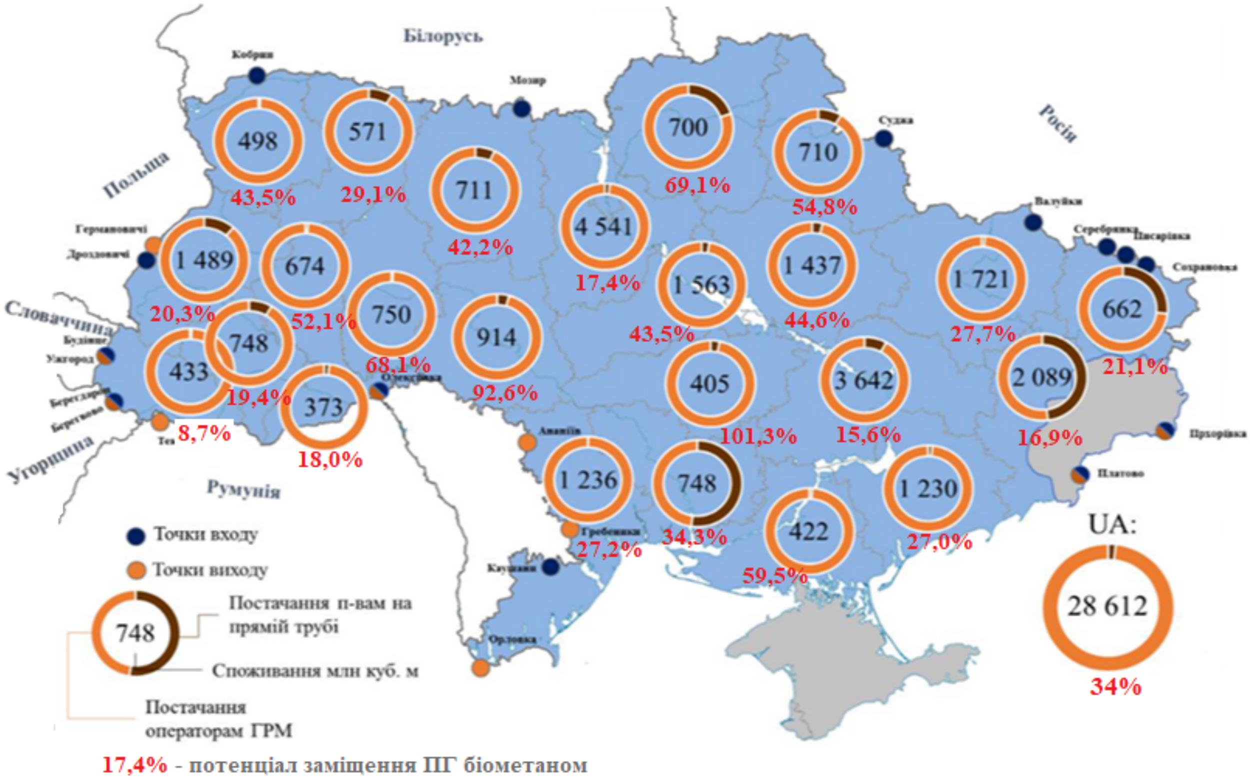


*Рис. 5.3 – Potential of NG substitution by biomethane in Ukraine by regions [[52]]*

From a technical point of view, supplying a certain amount of biomethane to NG grid is possible if at least three conditions are met in parallel, namely:

- biomethane quality compliance with the requirements of the GTS/GDS Codes and other regulatory documents;
- the physical possibility of NG grid to accept this volume of biomethane at the specified connection point (including summer period);
- sufficient pressure of biomethane at the entry point.

As already mentioned above, almost all commercial technologies of biogas upgrading to biomethane are able to ensure its proper quality for supply to GDS of Ukraine, and therefore this condition is currently not a deterrent for the implementation of biomethane projects.

The physical ability of a certain part of NG grid he gas network to receive a certain volume of biomethane may be limited by the actual regime of NG consumption. Thus, the average level of NG consumption in Ukraine in the winter period exceeds that in the summer period by 3 times (Fig. 5.4).

[52] Consumption of NG by regions of Ukraine in 2018, excluding gas production and gas transport companies. Source: Operator GTS.

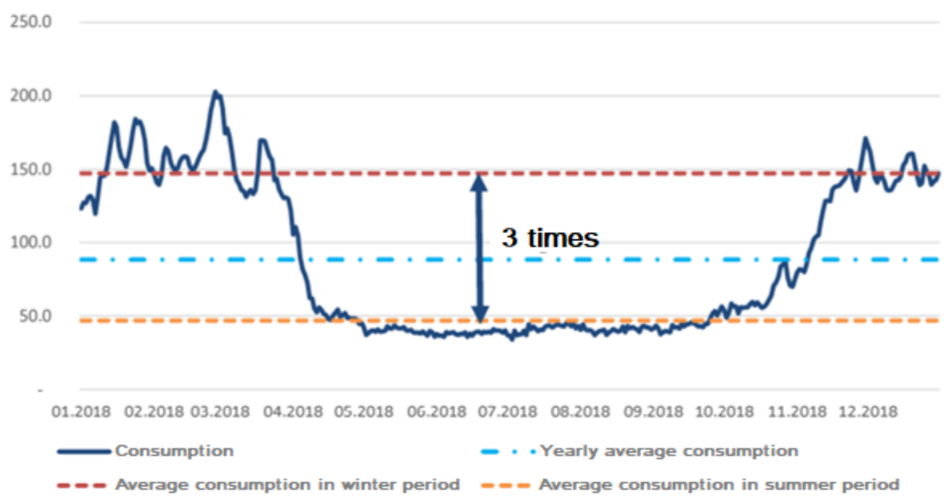


***Fig. 5.4 – Seasonal fluctuation of NG consumption in Ukraine in 2018. Source: data of GTS Operator***

As can be seen from the figure, the minimum daily consumption of NG in the summer period is about 40 million $m^3$/day. If this entire volume of consumption is replaced by biomethane with its uniform production throughout the year, the annual consumption of biomethane will be: 40 million $m^{3/}$day * 365 days/year = 14.6 bcm/year. If this consumption is replaced by 80% with biomethane, the annual consumption of biomethane will be 11.6 bcm/year. Both figures of potential biomethane consumption exceed the previously estimated biomethane production potential (9.7 bcm/year). That is, all the biomethane produced in Ukraine can potentially be supplied to the Ukrainian GTS/GDS.

A significant excess of winter NG consumption over summer will be characteristic of most parts of NG system, although the ratio may be different. A more even schedule of NG consumption is typical for grid with industrial NG consumers with relatively uniform consumption throughout the year.

Therefore, at the national level, the factor of difference between summer and winter NG consumption is not limiting for the supply of biomethane, however, at the local level of GDS there may be significant restrictions on the supply of biomethane especially in the summer period. It should also be taken into account that the actual volume of biomethane, which the GDS Operator will be able to accept in the summer period, will be even less than the consumption of NG, since the Operator must ensure the necessary level of diversification. As a first approach, the biomethane project can count on a maximum of 80% of summer NG consumption in a specific section of GDS.

There are also opportunities to increase the capacity of biomethane supply to the grid. Such possibilities are primarily related to the execution of NG grids redesign by the grid Operator by mean of their ringing and the additional connection among corresponding grid distribution points. The Operator will be able to make a decisions regarding network redesign in each specific case individually considering the scale of the biomethane project, the prospects of joining other similar projects, as well as own plans for such a redesign.

The possibility of increasing the capacity of receiving biomethane into the NG grid also exists when choosing another connection point, with correspondingly higher NG consumption. Since the biomethane project is territorially tied to the source of raw materials, choosing a connection point with a higher NG consumption will, as a rule, require an increase in the length of the biomethane pipeline, and in some cases, the necessary pressure of biomethane at the grid connect ion point. It should be borne in mind that all costs associated with bringing the biomethane supply pipeline to the point of connection with all necessary engineering structures and equipment should be covered by the investor of the biomethane project. The approximate cost of 1 km of gas pipeline is 1.0 - 1.5 million UAH, equivalent to 26 - 40 thousand euros.

As shown in fig. 5.5, the principle of operation of the branched gas network in Ukraine consists in the gradual reduction of throughput and pressure as the branch of the gas distribution system moves away from the branch of the gas transportation system.

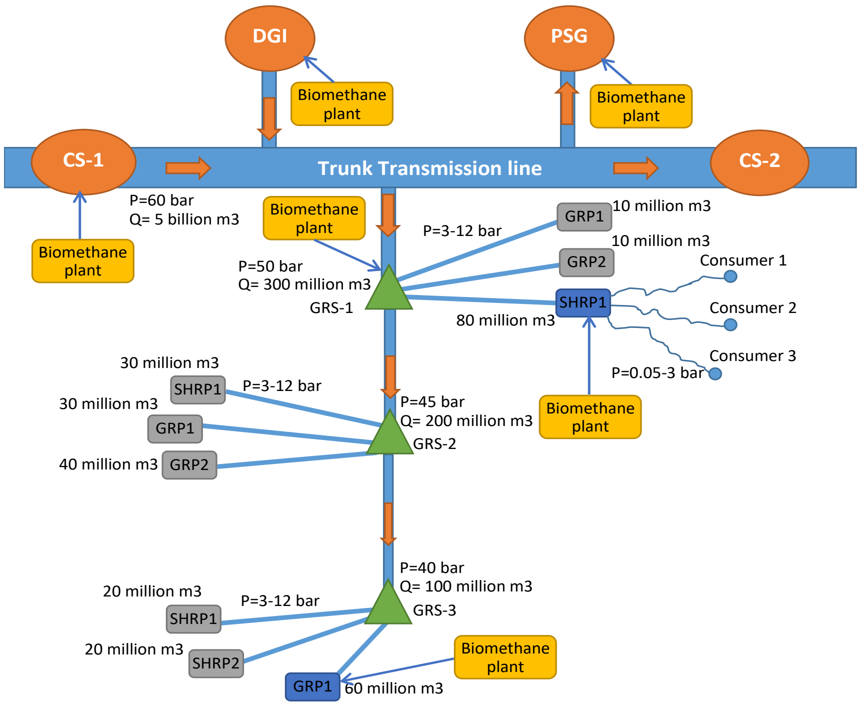


***Fig. 5.5 – The principle of operation of NG system in Ukraine [53]***

Thus, the pressure will be correspondingly higher at the connection points with a higher gas consumption capacity. From the point of view of the profitability of biomethane production, the pressure at the point of connection to the grid should be as low as possible, in order to avoid additional costs for the pressure station and electricity. However, for economic feasibility, especially for large projects (10 million $m^3$ of $CH_4$ per year and more), the construction of a pressurization station for biomethane may be reasonable.

The pressure in the final branches of GDS is, as a rule, 3-12 bar. Depending on the selected technology of biogas upgrading, the pressure of biomethane at the exit may be sufficient for supply to such sections of the gas grid. Thus, according to the technologies of pressure swing adsorption (PSA) and organic scrubber, the pressure of biomethane at the exit is ensured at the level of 4-7 bar, according to the technologies of water scrubber and membrane - 5-10 bar, but according to the technology of chemical scrubber only 0.1-4 bar [54]. If necessary, the biomethane project should include the construction of a biomethane pressing station.

[53] Source: Biomethane zoning and assessment of the possibility and conditions for connecting of biomethane producers to the gas transmission and distribution systems of Ukraine ( https://saf.org.ua/library/1548/ )

[54] Biomethane/ FNR, 2013 (https://mediathek.fnr.de/broschuren/fremdsprachige-publikationen/english-books/biomethane.html)

## 5.4 Priority zones for the construction of biomethane projects in Ukraine

On the basis of the analysis of gas consumption by points/zones/branches/agglomerations of GDS/GDP by individual consumers, an interactive map of priority zones for the location of biomethane plants was developed according to the established methodology at the level of each region of Ukraine (Fig. 5.6).

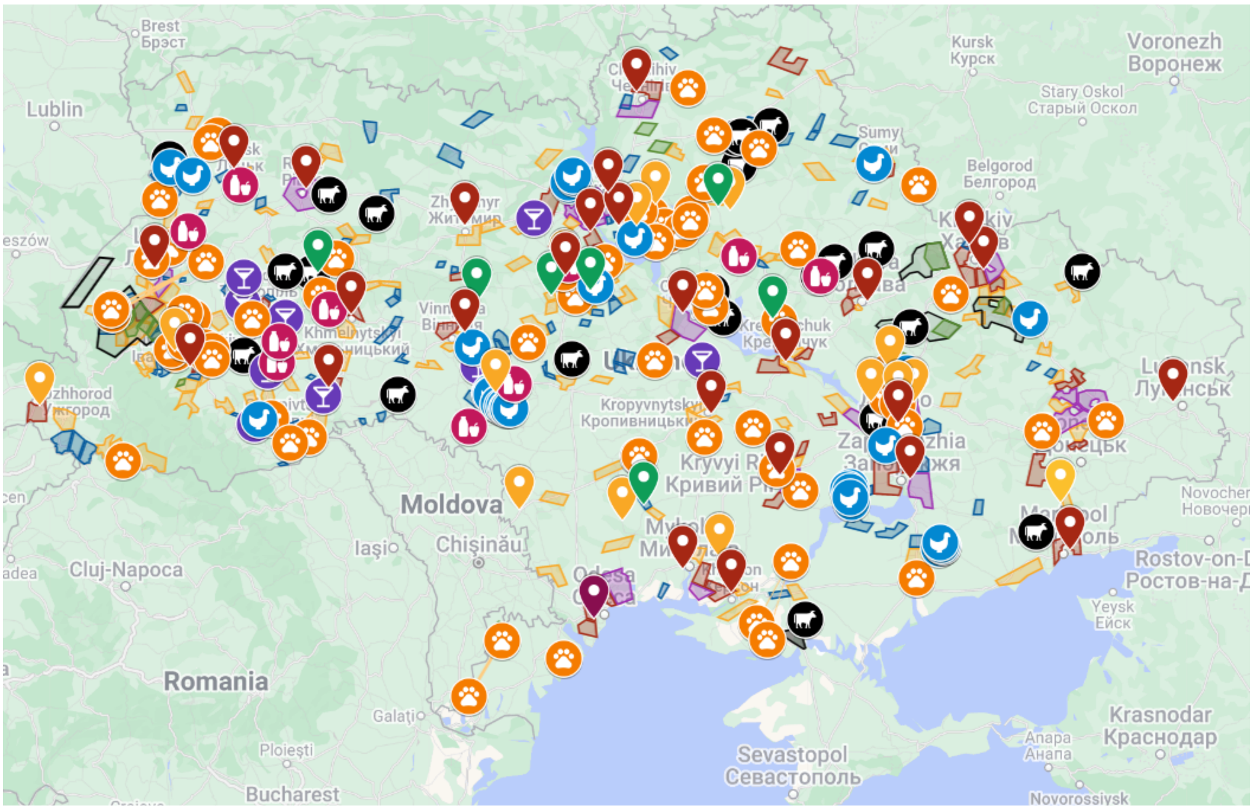


***Fig. 5.6 – Interactive map of the location of priority zones for connecting biomethane plants and the largest potential objects for the project implementation in Ukraine [[55]]***

The map includes more than 300 zones throughout Ukraine, sorted according to annual consumption and minimum monthly consumption for each zone. The map also shows zones along the GTS pipes (10-15 km wide) with no connection to any consumption (pink), as well as USNG zones and oil/gas production fields. The map also shows the locations of the largest livestock enterprises (pig farms, cattle farms, and poultry farms), alcohol and sugar factories, as well as biogas plants operating in 2021 in the agricultural sector and LFG recovery systems at MSW landfills.

The main conclusions that can be drawn from the conducted zoning are:

1) The total connection potential for the identified zones is 8.7 bcm/year (or 2.4 bcm/year based on the minimum monthly consumption);
2) The breakdown of gas consumption zones by scale and geographical location is rather uneven within Ukraine and highly dependent on local conditions;
3) The smallest consumption zone marked on the map has a potential of 2.7 million $m^3$/year, the largest - 800 million $m^3$/year;

[55] https://www.google.com/maps/d/u/0/edit?mid=1ttZ12uWjd2NxxH-xc3Lin61fN_4JrE1D&usp=sharing

4) The largest areas of consumption are concentrated near large industrial cities (Kharkiv, Dnipro, Cherkasy, Odesa, the industrial agglomeration of Donetsk region, Kyiv), around the GDS and GDP bushes and hydraulic fracturing networks (Rivne, Kyiv, Khmelnytskiy, Ivano-Frankivsk and Lviv regional rings), and also include individual regional industrial parks/private enterprises;

5) Large-scale zones of concentrated consumption are located in industrially developed and densely populated agglomerations (Dnipro, Kharkiv, Donetsk, Zaporizhzhya, Odesa, Cherkasy, Lviv, Kyiv regions); other regions (mainly the Center and West of Ukraine) are characterized by a smaller and more decentralized scale, but at the same time a denser distribution of zones (10-50 million $m^3$/year per bush of consumption) is more typical.

6) The lowest concentration of consumption is observed in Kirovohrad, Cherkasy, the northern part of Mykolaiv and Odesa regions, the northern part of Volyn, Rivne, Zhytomyr, and Kyiv regions (Polyssia zone).

7) Consumption for the minimum month (mainly summer time) is a key parameter that determines the scale of the biomethane project: for all 300 zones, the average ratio of monthly minimum and annual consumption is 1/44 (if the annual consumption is 10 million $m^3$/year, the average monthly minimum consumption is 227 thousand $m^3$/month), and for zones with a large share of industrial consumers, this ratio ranges from 1/14 to 1/36; for other zones (a large share of district heating or seasonal industry (for example, elevators, agriculture, grain drying, grain terminals, harbours, sugar factories, etc.), the ratio varies from 1/36 to 1/76 (in some in rare cases for the smallest zones or settlements as 1/100).

## 5.5 Preconditions for biomethane use in the motor fuel market

According to the State Statistics Service of Ukraine [[56]], only about 8.3 million tons of liquid motor fuels were consumed in 2020, with main share as diesel fuel (5.16 million tons or 62.1%) and gasoline - 1.69 million tons or 20.4% (Table 5.2). About 24.5 million $m^3$ of NG was consumed by road transport as CNG, which indicates the still insignificant potential of this market for biomethane producers.

About 80% of all liquid motor fuels are consumed in road transport, and about 14% in agriculture. The share of liquid biofuels, apparently bioethanol and/or biodiesel, was only 1%. Biogas/biomethane is still not used in transport in Ukraine.

The motor fuel market in Ukraine needs diversification along with a gradual increase in the share of renewable fuels. Along with bioethanol and biodiesel, biomethane can make a significant contribution to replacing fossil motor fuels. Biomethane can be a substitute for different types of motor fuels: compressed natural gas (CNG), gasoline, diesel, liquefied natural gas (LNG) and liquefied petroleum gas (LPG).

[56] ENERGY BALANCE OF UKRAINE (PRODUCT) FOR 2020 https://www.ukrstat.gov.ua/

### *Table 5.2 – The structure of the final motor fuel consumption in 2020*

| Final consumption by sectors | Gaseous fuels | | | Liquid fuels | | | | |
|---|---|---|---|---|---|---|---|---|
| | NG | Biogas | Share by sectors | LPG | Gaso-line | Diesel | Liquid biofuels | Share by sectors |
| | Mill m³ | | % | 000 t | 000 t | 000 t | 000 t | % |
| TOTAL | **17843.4** | **0.00** | | **1378.9** | **1690.5** | **5156.4** | **77.2** | |
| **Industry** | 3799.6 | 0.00 | 21.3% | 103.3 | 0 | 502.3 | 0 | 7.3% |
| **Transport** | 892.2 | 0.00 | 5.0% | 1224 | 1690.5 | 3569.7 | 77.2 | 79.0% |
| **Incl. roads** | 24.5 | 0.00 | 0.1% | 1224 | 1690.5 | 3547 | 77.2 | 78.8% |
| **others** | 10088.2 | 0.00 | 56.5% | 51.6 | 0 | 1083.6 | 0 | 13.7% |
| **Incl. agriculture** | 165.4 | 0.00 | 0.9% | 13.9 | 0 | 983.2 | 0 | 12.0% |
| **Share by fuel type** | 100% | 0% | | 16.6% | 20.4% | 62.1% | 0.9% | |

The most obvious application of biomethane as a motor fuel in Ukraine in the near future is its use in compressed form to replace CNG. For this, Ukraine already has the necessary infrastructure and a certain market for the consumption of this type of motor fuel. Interest in the use of CNG as a motor fuel is formed by number of operational and economic advantages, which are described in detail in the publication of UkrAvtoGas [[57]].

The total number of natural gas filling station (NGFS) in Ukraine is about 300 units, they are not evenly distributed over the territory of Ukraine (Fig. 5.7). The largest number of stations is located in the Donetsk, Luhansk and Dnipropetrovsk regions [[58]]. The average distance between NGFS in different settlements is about 100 km, and within the settlement - up to 15 km.

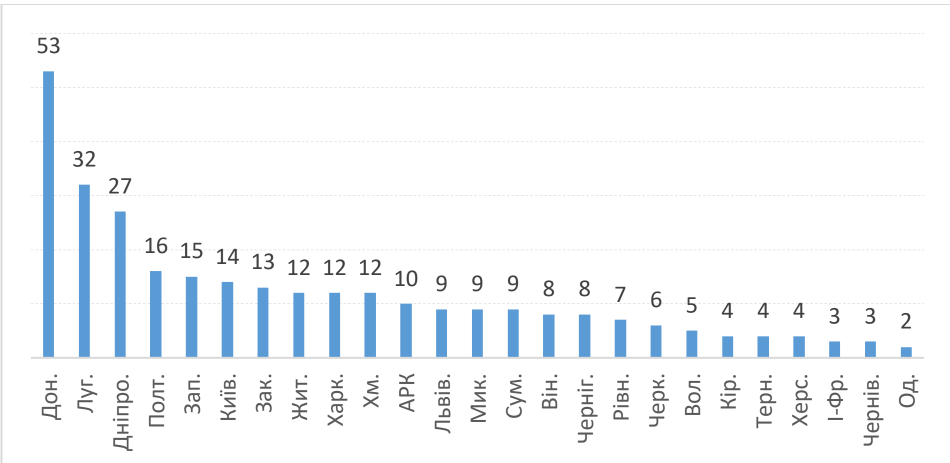


***Fig 5.7 – NGFS number by regions of Ukraine***

Both diesel and gasoline cars can be equipped with compressed biomethane supply units. Many car manufacturers today already have CNG vehicles in their model ranges. For example, Mercedes-Benz produces cars, commercial vehicles and trucks running on CNG. Various CNG models are also offered by Fiat, Skoda, Seat, Opel, Ford, Audi, Renault, Iveco, Scania, Volvo, Neoplan and others. Methane-powered agricultural machinery, such as New Holland and Massey Ferguson tractors, are also on the market.

[57] http://ukravtogaz.com/perevagi-metanu
[58] NGFS map https://agnks.org.ua/karta-agnks-ukrainy.html

Production of compressed gas does not require special licensing, however, design documentation with all operational safety measures must be developed for the installation of new NGFS. The main requirements include: the minimum distance to other facilities - 60 m, the presence of NG pipeline of the appropriate capacity and gas pressure, the presence of electricity supply with a permitted capacity at least 150 kW. The average project implementation period is 6-9 months. The estimated cost of the AGNKS-140 type delivery set with a productivity of 485 $m^3$/h with the development of project documentation is about 200,000 US dollars.

The use of compressed or liquefied biomethane in a number of EU countries has economic, environmental [59] and even reputational incentives. In particular, the obligation to introduce renewable fuels in EU countries stimulates the development of this market.

The market of renewable fuels in the EU can be considered promising for Ukrainian producers of biomethane, in particular the market of liquefied natural gas. The LNG market based on natural gas in the EU countries has been from 4 to 12.5 bcm per month for the past 3 years [60] and shows significant growth. Thus, in the 1st quarter of 2022, the growth was 72%, compared to the 1st quarter of 2021. Unlike Ukraine, the EU already has a fairly developed LNG consumption infrastructure, which continues to develop. Compared to fossil LNG, bio-LNG can reduce GHG emissions by approximately 92% and has the potential to even achieve negative greenhouse gas emissions [61].

The only type of incentive for the consumption of biomethane in transport in Ukraine is the factor of economic expediency. With the introduction of the biomethane registry in Ukraine, it can be expected that the use of biomethane from the NG grid as motor fuel will have a chance for development. At the same time, it will be possible to replace compressed natural gas with biomethane with guarantees of origin using the already existing infrastructure of NGFS.

It is obvious that there is a need to develop and implement mechanisms for financial and other types of support of biomethane production and consumption of biomethane as motor fuel in Ukraine. It is worth using the experience of countries where biomethane in transport is actively developing (Sweden, Italy, Finland, and Estonia).

The existing Energy Strategy of Ukraine until 2035 [62] does not contain any mention of biomethane as such, and in transport, in particular. Recently, the consumption of bioethanol and biodiesel has been actively lobbied, without special emphasis on biomethane.

State support for the development of biomethane requires the introduction of state goals and commitments regarding the biomethane share for the transport. The national energy strategy should include targets for the development of biomethane (for example, 5-10% of gas consumption in transport by 2030), as well as determine the number of gas stations operating on biomethane.

As part of this approach, government regulations could introduce a support scheme for biomethane fed into NG grids for further use in the transport sector. The scheme can be funded by fuel suppliers as part of biomethane/renewable fuel share commitments. The scheme can work using certificates for the production / consumption of renewable fuels. The implementation of the scheme requires the development of technical requirements and state standards for biomethane, which is used as motor fuel.

[59] https://ibbk-biogas.com/cng-mobility-challenges-and-opportunities-for-biomethane/
[60] https://globallnghub.com/report-presentation/status-of-european-gas-market-q1-review
[61] https://www.europeanbiogas.eu/reversing-the-trend-with-bio-lng/
[62] https://zakon.rada.gov.ua/laws/show/605-2017-%D1%80

# Chapter 6. Economics of biomethane projects

## 6.1 Cost of biomethane production

The cost of commercial biomethane has four main components, namely:

- expenses for biogas production,
- expenses for biogas upgrading to biomethane,
- expenses for biomethane correction to the parameters necessary for feeding into the GTS//GDS incl. odorization, compression, calorific value correction (if necessary)
- expenses for biomethane logistics to the GRS/HTS connection point to the, incl. costs of electrical energy for pumping through the pipeline, the cost of dispatching, etc.

The full cost of commercial biomethane can range from 300 to more than 1,000 euros per 1,000 $m^3$ (Fig. 6.1), depending on the price of raw materials and the project scale. Raw material costs, operating costs for biogas upgrading, and investments in upgrading station have the greatest influence on biomethane cost. A high cost of biomethane will occur for small project capacities and expensive raw materials.

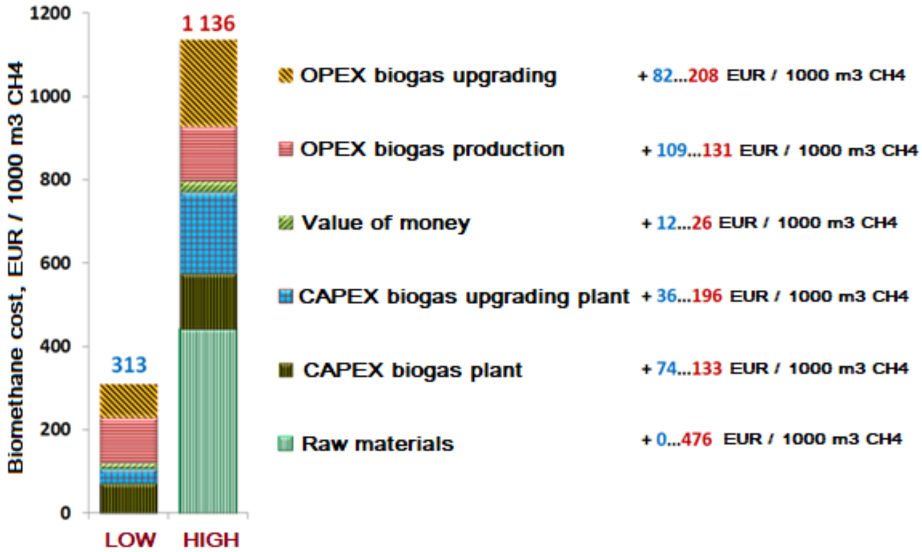


*Fig. 6.1 – Biomethane cost structure [63]*

The type of raw material and its price will have the most significant importance for the economy of the biogas project, since the costs of raw materials can reach 50% or more in the structure of operating costs. Further production of biomethane can be considered appropriate, if at least the raw material component of its cost price, taking into account the logistics costs, does not exceed the level permissible under the given conditions. So, for example, if the price of maize in the field is 40 euros/t and the transportation distance to the biogas station is 30 km, only the raw material component of biomethane cost can be about 500 euros/1000 $m^3$. Therefore, at a biomethane price of 700-800 euros/1000 $m^3$, projects using such a feedstock will be on the verge of payback.

[63] UABIO expert assessment

The necessary degree of biogas purification will depend, on the one hand, on the quality of "raw" biogas, and on the other hand, on the requirements for biomethane at the point of its entry into GDS or GTS. This will determine the choice of the appropriate upgrading technology. Today, there are 4 basic technologies for biogas upgrading to biomethane: membrane separation, absorption (water, chemical, physical), pressure swing adsorption (PSA) and cryogenic one. The cost of biomethane production depends to a greater extent on the capacity of the treatment plant, to a lesser extent on the type of technology.

As can be seen from fig. 6.2 specific investment costs are fairly closely correlated over a wide range of capacities for three technologies, namely PSA, water absorption and amine absorption. With small purification capacities, membrane separation is advantageous, and with an increase in upgrading capacity (up to 900-1000 $m^3$/h for "raw" biogas), the difference among the cost of various technologies is practically levelled out and amounts to 1700...1850 €/($m^3$/h), which in 0.9-1.2 times different from the investment in a cogeneration plant of the corresponding capacity. Thus, the investments in biomethane plant and in classic biogas plant with combined electricity/heat energy production biogas are similar.

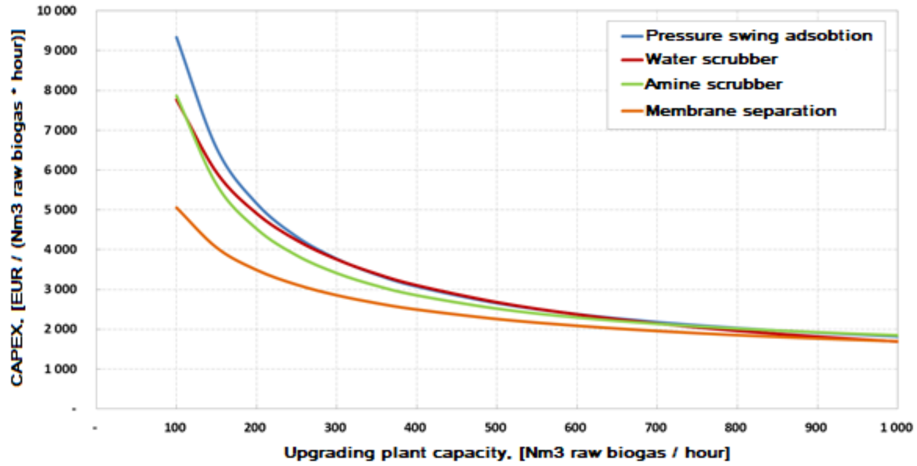


***Fig. 6.2 - Specific CAPEX of biogas upgrading to biomethane [64]***

Absorption by amines will be significantly more expensive in terms of operating costs, other technologies correlate quite well with this indicator in a wide range of capacities (Fig. 6.3). When upgrading biogas with PSA technology, the production cost of 1 $m^3$ of biomethane, depending on the capacity, will be from 7.6 to 14.4 euro cents, when using a water scrubber - from 7.5 to 16.8 euro cents, an amine scrubber - from 10.3 to 19.0 euro cents, and from 8.1 to 14.0 euro cents for with membrane separation.

In terms of 1 kWh of biomethane energy, its cost will be 0.79-1.50 €cent/kWh for PSA, 0.78-1.75 €cent/kWh for water scrubber, 1.08-1.98 €cent/kWh for amine scrubber, and 0.85-1.46 €cent/kWh for membrane separation.

[64] Novakovits, P & Doczekal, C (2016) "Biomethane tool for economic analysis of biogas production, gas upgrading and utilization of biomethane"

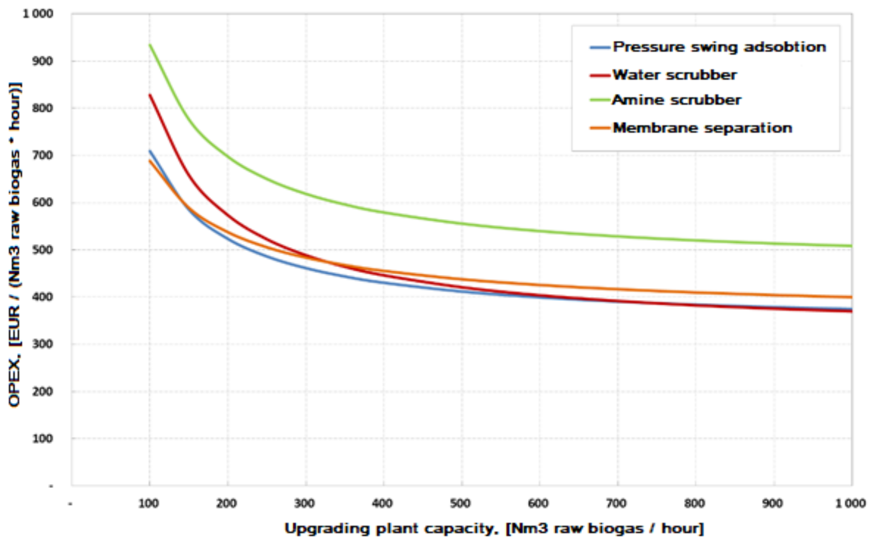


***Fig. 6.3 - Specific operating costs of biogas upgrading to biomethane***

The final cost of commercial biomethane will also be affected by the cost of its compression to the required pressure, odorization, quality monitoring (dispatching), calorific value adjustment (if necessary), as well as the cost of logistics.

If it is necessary to supply, for example, 10 million m$^3$/year of biomethane in the medium pressure network of 20-25 bar, the costs for the purchase of compressor stations can amount to 0.25-0.8 million euros, high pressure 40-45 bar - 0.5-1 .5 million euros (Table 6.1).

***Table 6.1 – Parameters and cost of NG compressors***

| Parameter | units | Option 1 | Option 2 | Option 3 |
|---|---|---|---|---|
| | | GTS | GTS brunches/GDS | GDS |
| **Annual biomethane production** | Mill m$^3$/year | 50 | 10 | 10 |
| **Capacity** | м$^3$/год | 6000 | 1200 | 1200 |
| **Input pressure** | bar | 1...3 | 1..3 | 1..3 |
| **Output pressure** | bar | 60...65 | 40...45 | 20...25 |
| **Price** | Mill euro | 2.5...3 | 0.5...1.5 | 0.25...0.8 |

## 6.2 NG grid connection cost

The cost of connection services provided by the GTS/GDS Operators consists of the cost of connecting the Customer facility to GTS/GDS and individual services (works) related to the connection.

The cost of connecting is determined by the GTS/GDS Operator in the connection contract in accordance with the Methodology for the formation of fees for connecting to gas transmission and gas distribution systems, approved by the Resolution of the NCSRECS No. 3054 dated 12.24.2015.

The standard connection fee includes, in particular, the service of installing a metering unit at the metering point to ensure its protection against adverse weather conditions and unauthorized access, as well as services of connecting external and internal gas supply networks and starting gas injection.

To encourage the connection of biomethane producers to gas distribution networks, the price of connection has been set by the RGK company [[65]] at the level of one UAH 1 [[66]].

It should be borne in mind that all other costs for bringing the biomethane pipeline to the point of connection to the GTS/GDS should be covered by the investor of the biomethane project. These costs will include the cost of pipeline, costs related to land acquisition, development of project documentation and any necessary engineering structures.

In order to connect to NG grid the investor of the biomethane project must contact NG operator according to technical design and conditions. The cost of the connection design will be UAH 180,000 as of August 2022, the equivalent of about 4,700 euros. According to the calculation approved by the Operator, the cost of work on the development and issuance of technical conditions for joining the GTS in 2021 amounted to UAH 19,345 (approximately 645 euros).

## 6.3 The cost of transporting biomethane through NG grid

In case of biomethane transportation through the GTS of Ukraine transportation costs will arise. Tariffs for NG transportation are determined by the GTS Operator. Thus, as of 2022, tariffs for NG transportation to EU countries across the border of Ukraine are set at USD 14.5-15.0 per 1,000 $m^3$ per day, without VAT, depending on the exit point [[67]]. Increasing and decreasing coefficients are also set for transportation services.

Thus, the fee is actually charged for the input capacity and not for the volume of gas transportation. For example, for a biomethane plant with a capacity of 1000 $m^3$/h, the cost of transportation to EU countries will be 348-360 thousand US dollars for the regulatory period (calendar year).

The GTS operator also sets tariffs for gas transportation within Ukraine. Thus, at the entrance to the GTS, the gas production enterprise will need to pay UAH 101.93 (EUR 2.7) per 1,000 $m^3$/day, and at gas exit points UAH 124.16 (EUR 3.3) per 1,000 $m^3$/day (without VAT).

## 6.4 The cost of biomethane storage in UGF

The following tariffs and coefficients apply to natural gas (biomethane) storage services:

1) Tariffs for services (without VAT):

- storage of NG - UAH 0.19 (approximately EUR 0.0063) per 1000 $m^3$ per day;
- NG input - UAH 110.16. (approximately EUR 3.66) per 1000 $m^3$ per day;
- NG output - UAH 63.41 (approximately EUR 2.11) per 1000 $m^3$ per day.

2) Coefficients applied to tariffs for natural gas input, output and storage services:

- coefficient that takes into account the order of individual services for a period of one month at the level of 1.1;
- coefficient that takes into account the order of individual input and output services a day in advance at the level of 1.2.

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[65] Operator of GDS

[66] https://glavcom.ua/new_energy/news/biometanovi-zavodi-zmozhut-prijednatis-do-gazorozpodilnih-merezh-za-1-grn-856498.html

[67] https://tsoua.com/kliyentam/taryfy-na-transportuvannya-gazu/

## 6.5 The sale price of biomethane

At the moment there are three main possible options for selling commercial biomethane, namely:

1. Selling on the domestic market under supply contracts between the biomethane producer and another business entity.
2. The potential possibility of virtual export of biomethane to EU countries using the national biomethane register, or under direct contracts with traders using guarantees of origin (GoO) of biomethane.
3. Physical export at the contract price, including export of liquefied biomethane and biomethane supplied through the GTS.

The price of biomethane, which will be sold according to the virtual export scheme, will most likely be formed according to the formula:

*Biomethane price = Exchange price of NG + Premium*

Exchange prices for NG on the EU market [[68]] in August 2022 fluctuated between 192-206 EUR/MWh, and by the end of the month reached a historical maximum of 320 EUR/MWh (equivalent to approximately 3200 EUR/1000 m$^3$ biomethane) [[69]]. At the same time, at the end of June 2022, prices were at the level of EUR 134/MWh. With such a sales scheme, the price of biomethane will depend on the price of natural gas, and when the latter falls, it may drop to an unacceptable level.

The GoO premium for biomethane is voiced by potential biomethane traders at the level of 100-600 euros per 1000 m$^3$ depending on the type of raw material from which biomethane is produced. Therefore, the total tariff for biomethane in the current market conditions would be at least 2,000 euros/1,000 m$^3$, and the profitability of biomethane production projects in Ukraine would be quite high, at a level not lower than 30% IRR and with a payback period of less than 3-4 years.


***Fig. 6.4 – Exchange prices for natural gas in the EU in July-September 2022 [[70]]***

It is difficult to predict changes in NG prices even in the medium term. However, with the implementation of the Green Deal framework agreement in the EU, we should probably not expect low level of NG prices as, for example, in 2020. Thus, the National Bank of Ukraine (NBU) predicts that the average annual price of NG at the TTF hub in the Netherlands will be $1,314.5/1000m$^3$ in 2022. This is stated in the NBU's

[68] Day-Ahead Market
[69] Spot market data | Powernext
[70] https://www.powernext.com/spot-market-data

"Inflation Report" for July 2022. According to the forecast, NG prices will be $1,283.5/1000m$^3$ in 2023 and $1,007.3/1000m$^3$ in 2024.

Some traders offer the purchase of biomethane at a price fixed for a long period (up to 15 years). The offered prices are 1050 - 1100 Euro/1000 m$^3$. With such a purchase scheme, the risk of instability in the NG price is taken by the buyer.

# Chapter 7. Legislative aspects of biomethane market development

## 7.1 Development of the biomethane market

The war in Ukraine make it necessary to accelerate the search for ways to replace imported natural gas. In this regard, the issue of the development of biomethane production in Ukraine remains relevant, its importance has even increased.

The Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Development of Biomethane Production" [[71]] provided that the Cabinet of Ministers of Ukraine within six months from the date of entry into force of this Law must ensure the adoption of the Procedure for the Biomethane Register operation and the bringing of normative legal acts into compliance with this document. On July 22, 2022, the CMU adopted Resolution No. 823, which regulates the functioning of the biomethane register. After that, the State Energy Efficiency Agency must launch a biomethane register within six months.

UABIO believes that the Procedure for the functioning of the biomethane register should provide the possibility for biomethane producer to enter into the register information on the compliance of biomethane with sustainability criteria by uploading a copy of the certificate of compliance of biomethane with sustainability criteria, obtained in accordance with the rules of one of the voluntary certification schemes recognized by the European Commission. This will provide an opportunity for biomethane producers to confirm compliance with sustainability criteria in accordance with the requirements of EU Directive 2018/20013 of December 11, 2018.

On August 2, 2022, the NCSRECS adopted a Resolution on reducing the requirements for the molar fraction of oxygen in natural gas from 0.02 mol.% to 0.2 mol.%, which should ensure the access of biomethane to GTS and to 1.0 mol. % for access to GDS. With this resolution, the Regulator makes appropriate changes to GTS and GDS Codes.

## 7.2 Road map for biogas/biomethane sector development in Ukraine

Current Ukraine's Energy Strategy sets an ambitious goal of achieving 11 Mtoe of biomass, biofuels and waste in the total supply of primary energy in 2035. It corresponds to 11.5% of the total primary energy supply. Biogas and especially biomethane will play important role in this development.

Expert estimates show that the total biogas production could reach 1.6 bcm in 2030. The significant part of that biogas could be upgraded to biomethane. Total biomethane production could be 1.0 bcm in 2030. It is expected that biomethane could partly (0.5 bcm) be exported to the EU. The rest could be utilized locally for combined heat and electricity generation in CHP units (0.2 bcm), heating and industry applications (0.22 bcm) and for transportation purpose (0.08 bcm).

Total biogas and biomethane production could be at the level of 6.0 bcm by that date. Only 25% of total amount (1.5 bcm) may be used as raw biogas for combined heat and electricity production. The rest of biogas could be upgraded to biomethane (4.5 bcm). It is expected that biomethane will still be important as export product (2.3 bcm) to the EU. The rest could be utilized for local purpose.

[71] https://zakon.rada.gov.ua/laws/show/1820-IX#Text

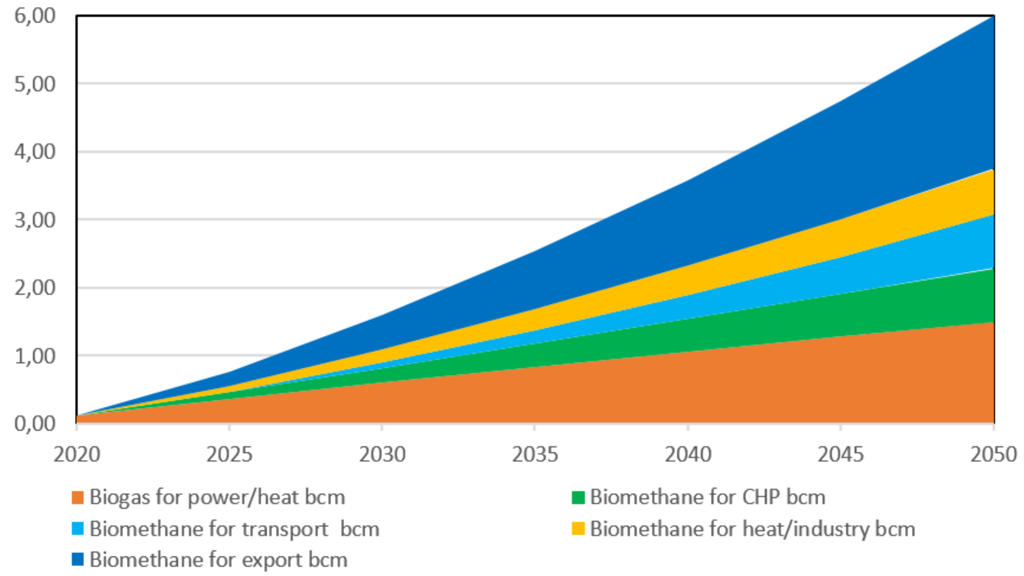


***Fig. 7.1 – Annual biogas and biomethane production, bcm $CH_4$ (прогноз forecast)***

This vision of short-term and long-term goals has been developed by UABIO and requires further discussion by all stakeholders, including the ministries, government agencies, NG system operators and private business.

New biogas production will be based, in particular, on the use of agricultural by-products for anaerobic digestion, but new technologies and raw materials will also play a role. They may include thermal gasification of lignocellulosic feedstock obtained in agriculture and forestry, as well conversion of renewable electricity into green hydrogen. In energy systems with a large share of RES, excess electricity can be used to produce hydrogen by electrolysis of water followed by its methanation with carbon dioxide, which is obtained in the process of biogas upgrading.

The increase in production and use of biomethane will include:

- Transition of existing biogas plants to biomethane production.
- Increasing efforts to use more agricultural waste for biomethane production.
- Increasing the use of biomethane as a fuel for heavy road and water transport.
- Joining Ukraine to the European biomethane trading system and creating relevant new market opportunities.

Biomethane is an alternative for the use of NG or its derivatives not only for energy, but also for the chemical industry. It is important to identify and demonstrate the potential of biomethane in the chemical industry.

**Short-term actions (2022-2023) may include:**

1. Start of operation of the biomethane register (February 2023).
2. Signing of an agreement on mutual recognition of guarantees of origin of biomethane between the biomethane registry of Ukraine and the European biomethane registry ERGaR.
3. Legislative regulation of using digestate from biogas plants as an organic fertilizer or soil improver.

4. Commissioning of the first biomethane plants in Ukraine (up to 5 by the end of 2023).

**Medium-term actions (2030) may include:**

1. Creation of a medium-term vision and legislative incentives to promote the use of biomethane in the transport sector.
2. Production of up to 1 bcm/year of biomethane by 2030.
3. Starting the use of biogas and biomethane as flexible capacities to regulate the load of energy system.
4. Development and adaptation of the Roadmap for the development of bioenergy, including biomethane, until 2050 and the Action Plan at least until 2035.
5. Introduction of separate collection of the organic fraction of MSW with subsequent production of biogas/biomethane.
6. Introduction of first biomethane plants combined with green hydrogen production and methanation plants.
7. Starting the use of biomethane in transport (bio CNG and bio LNG).

**Long-term actions (2050) may include:**

1. Adaptation/redesign of the Ukrainian GTS/GDS for biomethane use.
2. Production of up to 4.5 bcm/year of biomethane by 2050.
3. Expansion of the network of bio CNG and bio LNG filling stations.
4. Creation of legislative incentives to stimulate the use of biomethane for the chemical industry.

## Previous publications of UABIO

### All UABIO`s Position Papers are available at:

- https://uabio.org/materials/uabio-analytics/ (Ukrainian language);
- https://uabio.org/en/materials/uabio-analytics/ (English language).

## Bioenergy Association of Ukraine (UABIO) is a nonprofit civic union that unites business and experts for sustainable bioenergy development in Ukraine

**9** Years

**35** Companies

**7** Individuals

**20+** Experts in Ukrainian Bioenergy

We participate in the development of legislative, state and sectoral strategic documents that contribute to bioenergy development in Ukraine; we provide expert, advisory and information assistance to partners; we monitor national and international legislation in bioenergy, renewable energy, energy efficiency, and climate change; we cooperate with international associations, organizations, business, experts, government representatives; we organize public events: conferences, workshops, and seminars; we raise the Ukrainians level of awareness about the bioenergy benefits through the website, social networks, and digest.

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