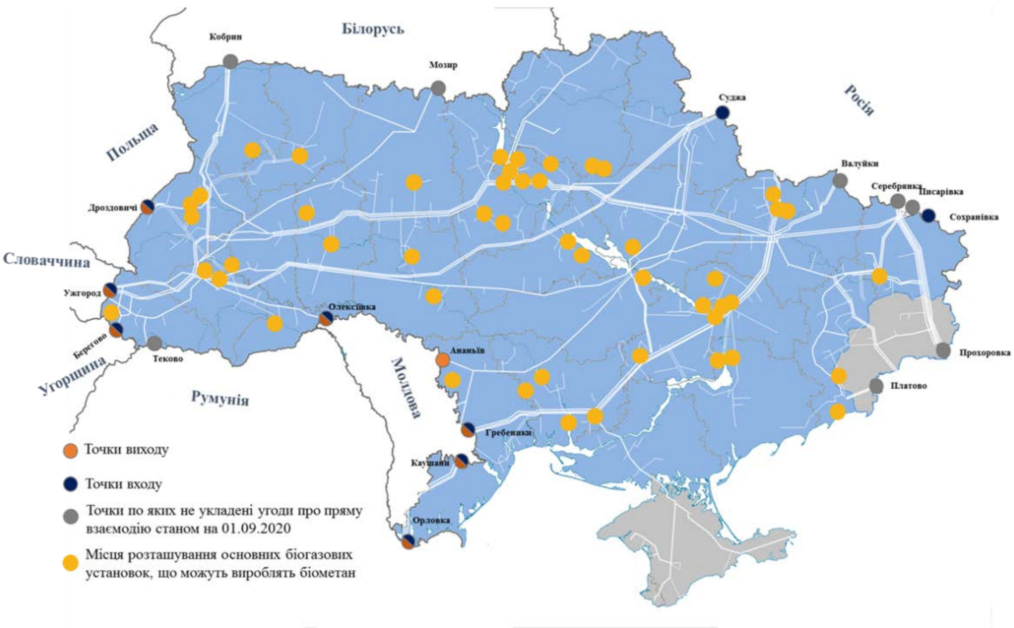

BIOMETHANE ZONING AND ASSESSMENT OF THE POSSIBILITY AND CONDITIONS FOR CONNECTING OF BIOMETHANE PRODUCERS TO THE GAS TRANSMISSION AND DISTRIBUTION SYSTEMS OF UKRAINE

FINAL REPORT

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Content

Annexes

Acronyms

AD	Anaerobic Digestion
BSG	Spent grain
CAPEX	Capital Expenditures
CHP	Combined Heat and Power
CMU	Cabinet of Ministers of Ukraine
CS	Compressor station (on transmission pipeline)
DGI	Debit gas installations
DH(S)	District Heating (Systems)
EBRD	European Bank Reconstruction and Development
GDP	Gross Domestic Product
GDS	Gas Distribution System
GHG	Greenhouse Gas
GRP	Ukrainian equivalent «ГРП» – газорегуляторний пункт – gas regulation substation
GRS	Ukrainian equivalent «ГРС» – газорозподільна станція – gas distribution station
GPU	Gas preparation/production unit
GTS	Gas transit/transmission system
HAPP	Hydro-Accumulation Power Plant
HPP	Hydropower Plant
IRR	Internal Rate of Return
LFG	Landfill Gas
MBT	The Mechanical Biological Treatment of waste
MCTDU	Ministry of Communities and Territories Development of Ukraine
MENRU	Ministry of Ecology and Natural Resources of Ukraine
MSW	Municipal Solid Waste
NCV	Net Calorific Value
NG	Natural gas
NGO	Non-Governmental Organization
NPC	National Power Company
NPV	Net Present Value
OPEX	Operational Expenditures
PSG	Ukrainian equivalent «Підземні сховища газу» - underground gas storages

RES	Renewable Energy Sources
RGK	Ukrainian equivalent «Регіональна газова компанія» - name of Ukrainian gas distribution company "Regional Gas Company" (Ukrainian commercial company which integrates several regional gas supply companies)
SAEE	State Agency on Energy Efficiency and Energy Saving
SBP	Sugar Beet Pulps
SHRP	Ukrainian equivalent «ШРП» - шафовий газорегуляторний пункт – module gas regulation substation
TPP	Thermal Power Plant
TSO	Transmission System Operator
VAT	Value Added Tax
VS	Volatile Solid
WWTP	Waste Water Treatment Plant

Units of measurement

ºC	Degrees Celsius
CO_2-eq.	Carbon Dioxide equivalent
GWh	Gigawatt-hour
ha	hectare
EUR	Euro (€)
kt	thousand tons
ktoe	thousand tons of oil equivalent
kWh	kilowatt-hour
Mt	Millions of tons
Mtoe	Millions tons of oil equivalent
MW	Megawatt
MWh	Megawatt-hour
toe	tons of oil equivalent
USD	United States Dollar

Introduction

There is considerable untapped potential for a wide spread implementation of biogas and biomethane projects in Ukraine. The Ukrainian natural gas transportation system (GTS) is internationally connected potentially enabling biomethane and other renewable gases physical or virtual delivery from Ukraine to Western Europe. At the moment there is a downward trend in the transit of natural gas to Europe by Ukrainian GTS. Ensuring the maximal possible load of the Ukrainian GTS with natural gas of own production and alternative renewable gases is urgent.

Ukraine has the largest area of agricultural land in Europe, one of the highest agricultural areas per capita and developed agriculture industry. Using biomethane as a motor fuel is an excellent opportunity for agricultural producers to obtain own energy source by means of waste and secondary products of their own production.

The use of biomethane for public transportation can significantly improve air pollution in large cities. However, so far there are any examples of biomethane use for transportation in Ukraine including both separately or blending with natural gas.

Ukrainian biogas sector should be strongly integrated into the modern energy system and network. Besides that, the sector should hold a strong foothold in national the nutrient recycling activities and participate in the archiving of the national target of greenhouse gases emission reduction.

Using the capabilities of the Ukrainian GTS connected to European GTSs and, in the long term, virtual export to the EU market, could improve the economic attractiveness of biomethane production in Ukraine. Development of the Ukrainian Register for biomethane production and utilization and cooperation with similar Registries of EU countries is the potential possibility to exchange the biomethane Guaranty of Origin (GoO) with other countries.

This study is executed by initiative and financial support of European Bank of Reconstruction and Development (EBRD) to prepare assessment of the biomethane production potential and conditions for use in the gas transmission system of Ukraine, and to support partnership, knowledge sharing and marketing activities to promote for biomethane production and use.

This mid-term report represent intermediate result of the study recovered mainly Task A1 “Assessment of the biomethane production potential at the level of individual regions (oblasts) of Ukraine”.

Assessment of the biomethane production potential at the level of individual regions (oblasts) of Ukraine

Potential for biomethane production from waste and secondary products of agriculture and municipalities origin by implementation of anaerobic digestion technology

Feedstock for biomethane production

A variety of organic materials can potentially be used for biogas production, including raw materials (specially grown crops), by-products and wastes from plant and animal products, animal husbandry wastes, and anthropogenic wastes.

Assessment of biomethane production potential in Ukraine covers the following types of organic materials:

1. Cattle manure formed during animal keeping at the enterprises.
2. Pig manure formed during animal keeping at the enterprises.
3. Poultry litter formed during animal keeping at the enterprises.
4. Maize silage, specially grown.
5. Crop residues of major crops, including wheat, rye, barley, maize, sunflower, soybean, rapeseed, and sugar beet.
6. By-products and wastes of target production by enterprises of food processing industry.
7. Sewage sludge from municipal treatment facilities.
8. Organic fraction of solid waste.

Methodological approaches

Animal husbandry wastes

The basic approach in estimation the availability of animal husbandry wastes (manure, litter) is using the national statistical data on the livestock available at the industry farms (enterprises)[1]. The reported livestock number on the date assumed to be the average livestock number within a year.

Since 2015, statistics on the number of animals for the temporarily occupied territories (TOT) and the Autonomous Republic of Crimea are not available. To take into account these territories of Ukraine in the total potential of biomethane production, an approximate estimate of the livestock that can be kept there until the beginning of 2021 has been made.

The latest relevant data of the State Statistics Committee on the number of animals for the entire territory of Ukraine are given on January 1, 2014. With some assumption, it is estimated that the difference in livestock between 2015 and 2014 for Donetsk and Luhansk regions shows the number of animals remaining on the uncontrolled territory of Ukraine. Livestock at the level of 2014 is taken

[1] Number of agricultural animals as of January 01, 2021. State Statistic Service of Ukraine, 2021

as the basic value for the AR of Crimea. The number of livestock estimated in this way for the AR of Crimea and the temporarily occupied territories of Ukraine has been adjusted as of 2021 for the growth / decline rate of livestock, which occurred in Ukraine in general from 2014 to 2021.

Subsequently, the formation of manure given as the average number for mixed age groups of animals in the breeding cycles.

Further, the technical availability for manure collection is basically defined by current practices of livestock keeping at the enterprises. The data on livestock manure/litter handling practices was taken into account[2]. Uncertainty reduction factor of 0.93 chosen for all types of animals waste (table 1.1).

Table 1.1 – Parameters used for manure and litter

Feedstock type	**Specific VS formation[3,4,5],** kgVS/day/head	**Technical availability for collection,** %	**Collected feedstock,** % to technical availability	**Methane yield potential[6],** $_Nm^3CH_4/kgVS$
Cattle manure	4.04	53	93	0.193
Pig manure	0.46	100	93	0.45
Poultry litter	0.0356	100	93	0.32
Sheep and goats litter	0.88	27	93	0.19

Maize silage

Potentially, maize silage can be grown in large quantities, which will be limited only by available land area and crop yield. From the point of view of sustainability of agricultural practices and the trend towards the production of second-generation biofuels from by-products and waste, such an approach can be justified only by the expediency of significantly increasing biogas production in the short term. The use of 10% of arable land (3.27 mln hectares) in Ukraine with an average yield of silage maize for biogas of 40 t/ha in potential could give 13-14 billion CH_4 per year.

The potential of maize silage cultivation for biogas production in this study connected to the potential of manure and litter formation. The unified approach is mixing 60% maize silage with 40% manure or litter by raw mass. Additionally, at regional level the average crop harvesting for the period of 2013-2016 in the regions used to estimate the needed area for maize silage production.

Specific VS formation for maize silage is assumed 0.285 tVS/t raw mass. Specific CH_4 yield – 0.365 $_Nm^3CH_4/kgVS$[7].

Crop residues

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[2] Consultant`s data

[3] ВНТП-АПК-09.06 “"Systems of removal, processing, preparation and use of manure" / Ministry of Agrarian Policy of Ukraine. - Kyiv, 2006. (in Ukrainian)

[4] Preparation and processing dung on poultry farms. Research and practical recommendations / Ed. Kuznetsova V.F. – VNYTYP (ВНИТИП), 2006, 108 p. (in Russian)

[5] НТП АПК 1.10.06.002-00 “"Designing the rules of technology design of the farms…" / Ministry of agriculture of the Russian Federation, Moscow .: 2001 (in Russian)

[6] Methods of generalized assessment of technically achievable energy potential of biomass / Dubrovin VO, Golub GA, Dragnev SV, Geletukha GG, Zhelezna TA, Matveev YB, Kucheruk PP ., Kudrya SO, Zabarny GM, Maslyukova ZV - К .: Тов. Viol-print, 2013. - 25 p.

[7] Handreichchung. Biogasgewinnung und -nutzung. FNR. - Gulzow, 2006. – 232 pages.

Estimation of crop residues value is based on the national statistical data on production of the main crops[8]. To take into account the potential use of crop residues generated in the temporarily occupied territories of Ukraine, the data of the interactive online map EOS[9] and the data of the State Statistics Service for 2013 and 2019 on the cultivation of major crops were used.

The data of the interactive map show the total area of the fields under different crops, with the distribution by regions of Ukraine, taking into account the temporarily occupied territories and the AR of Crimea. The difference between the total area of land under a separate crop for Donetsk and Luhansk regions from EOS maps and the total area of land under a similar crop from official data of the State Statistics Service for 2019 roughly shows the total area of fields under a single crop in the occupied territories. According to the AR of Crimea, the data of EOS maps as of 2019 are taken as a basis. To estimate the area of land serviced by agricultural enterprises in the occupied territories, their shares in the total area of land under individual crops, which correspond to the data of the State Statistics Committee for Donetsk and Luhansk regions for 2019, were accepted. The shares of fields served by agricultural enterprises for the AR of Crimea were accepted according to the State Statistics Service as for 2013.

To assess the harvesting potential of the main crops in the occupied territories and, accordingly, the formation of crop residues, data on the yield of individual crops in the relevant regions of Ukraine as of 2019 were used. For the AR of Crimea, the yield is accepted at the level of 2013.

The yields of biomass tied to commodity crops production via corresponding rates given in the table 1.2.

Table 1.2 – Parameters used for crop residues

Feedstock type	**Theoretical crop residue yield[10,11]**, ton per ton of commodity crop	**Technically available for collection crop residue yield[9], %** to theoretical crop residue yield	**Share accounted for biogas production**, % to technically available for collection crop residue yield	**Methane yield potential[12,13,14,15]**, $_{N}m^3CH_4/t$
Wheat straw	1	60	50	230
Rye straw	1	60	50	230
Barley straw	0.8	60	50	230
Maize stalks	1.3	70	43	140

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[8] Production of agricultural crops in 2019. State Statistic Service of Ukraine, 2021

[9] https://eos.com/cropmap/

[10] Georgiy Geletukha, Tetiana Zheliezna. Prospects for the use of agricultural residues for energy production in Ukraine // UABio Position Paper N7. – 2014. – 33 p.

[11] Kolchina L.M. Technologies and equipment for the cultivation and harvesting of sugar beet: a reference book. - M .: FGBNU "Rosinformagrotech", 2012. - 80 p. (in Russian)

[12] Kucheruk P., Matveev Yu., Rudska V. Experimental study of biogas yield from straw in anaerobic digestion process // Renew. Energy. – 2018. - №2. – p. 88-97. (In Ukrainian)

[13] Consultant`s data.

[14] https://kineticbiofuel.com/wp-content/uploads/2018/10/Brochure-FINAL-2017.pdf

[15] https://www.researchgate.net/publication/347108887_Anaerobic_Digestion_of_Steam-Exploded_Wheat_Straw_and_Co-Digestion_Strategies_for_Enhanced_Biogas_Production

Sunflower stalks and cobs	1.9	67	40	53
Soy straw	1	70	43	191
Rape straw	2	70	43	135
Sugar beet tops	0.45	90	100	38

The crop residue yield indicator shows the specific theoretical mass of the plant, which is generated at the time of harvest per unit mass of the target product (grains, roots). The technical potential of the collection takes into account only the part of the plant that can be collected by traditional technical means of collection. The rest of the unharvested mass of the plant actually remains in the field and is plowed. The assessment of the potential use of crop residues for biogas production takes into account the part of collected biomass as given in the Table 1.2.

This approach is conservative and takes into account the potential alternative consumption of crop residues (as bedding for livestock farms, as a substrate for growing mushrooms, as a building or industrial material, as a solid renewable fuel, etc.) or their direct application to fields to replenish humus balance.

However, ultimately the whole mass of collected crop residues can be used for biogas production without any substantial influence for the crop cultivation. It is well known that organic matter is converted via anaerobic digestion process resulting in biogas release composed mainly from methane and carbon dioxide. So, almost whole mass of nutrients and approximately a half of an organic carbon in raw matter is contained in digested material, which is as a rule returned to the field in the converted forms ready to use by plants. Using this approach will give even higher biomethane production potential from crop residues – up to 10.5 billion m^3 CH_4 per year.

Food industry by-products

By-products are formed in the process of primary processing of crop products. The most significant branches of food and beverage industries in Ukraine are analyzed for potential use of by-products for biomethane production as following:

- sunflower oil production,
- sugar production,
- flour and cereals production,
- distilleries,
- breweries,
- dairies.

Sugar production

The main types of by-products originated from sugar production are sugar beet press (SBP) and molasses. Estimation of SBP formation tied to sugar beet production (for processing) in all the categories of agricultural enterprises[16]. Sugar beet production in temporarily occupied territories of

[16] Harvesting of industrial crops in 2019. Sugar beet (for processing). State Statistic Service of Ukraine, 2021

Ukraine was estimated based on the data on land area under sugar beet according to the maps of EOS and yield of sugar beet in Crimea as of 2013.

Table 1.3 – Parameters used for sugar production residues

Residue type	Residue output per 1 ton sugar beet processed[17]		Methane yield potential[18]	Share accounted for biogas production
	tons of RM	tons of VS	$_{N}m^3CH_4/tVS$	% to residue output
SBP	0.806	0.0627	450	75
Molasses	0.044	0.0318	315	25

Flour & Cereals production

With flour and cereals production, the different types of by-products and wastes are generated including grain shorts, bran, husks, unconditioned grains, flour powder, etc.

Processing of different kind of cereals gives different volumes of by-products. The average generation rate for all cereals produced in Ukraine estimated as 0.607 tons per ton, and 0.333 tons per ton of wheat flour produced.

In this study, the data on production of bran, sharps and other residues[19] are used to estimate biomethane production potential. These residues formed from the sifting, milling or other treatment of different cereals including maize, wheat, rice and other. The accounted mass of bran, sharps and other residues is 752.15 thousand ton in 2019. The production of flour&cereals residues in temporarily occupied territories of Ukraine were estimated in proportion to the field areas under the main grain crops.

The average specific VS formation for flour&cereal by-products is assumed 0.8 tVS/t raw mass. Specific CH_4 yield – 0.150 $_{N}m^3CH_4/kgVS$[20]. Biogas potential from flour&cereal by-products estimated for 50% of theoretically generated mass.

Distilleries

In distilleries, the main waste types formed are potato, stillage, grain stillage and molasses stillage. The first two types of stillage used mainly as a fodder because of its high nutritive value, however it needs drying and granulating as additional processing. Molasses stillage is the final waste what is reasonable for entirely utilization for biogas production.

As there are no available statistical data on the volumes of spirit production, stillage production rate considered as unique value for different types of stillage, with methane yield potential 360 $_{N}m^3CH_4/tVS$ (table 1.4). In 2019, the production of spirit in Ukraine estimated by Pro-Consulting as 149.1 thousand ton[21]. No data are available on the regional distribution of spirit production. Since,

[17] Consultant`s data

[18] Consultant`s data

[19] Output industrial products, by type and regions in 2019. State Statistic Service of Ukraine, 2021

[20] Consultant`s estimate

[21] https://pro-consulting.ua/ua/issledovanie-rynka/analiz-rynka-spirta-v-ukraine-2019

data on spirit production in temporarily occupied territories of Ukraine were also not taken into the account.

Table 1.4 - Parameters used for distilleries by-products

Residue type	Residue output per 1 ton spirit produced[22]		Methane yield potential[23]	Share accounted for biogas production
	tons of RM	tons of VS	$_{N}m^3CH_4/tVS$	% to residue output
Stillage	13.650	0.960	360	75

Breweries

In breweries, the main by-product is spent grain. Brewery spent grain (BSG) is mostly used as a fodder, for bakery macaroni foods, confectionery production etc. Besides, it is can be used as raw material for biogas production.

The statistical data on beer produced from malt (excluding non-alcoholic beer, beer containing ≤ 0.5 % by volume of alcohol, alcohol duty)[24] used as a base for calculating biomethane potential from BSG. To account potential from BSG in temporarily occupied territories of Ukraine additional 5% to general beer production in Ukraine was used for Donetsk region (Efes brewery in Donetsk), 0.5% - for Luhansk region (Luhansk brewery in Luhansk) and 0.5% - for AR Crimea (Crimea brewery in Simferopil).

Table 1.5 - Parameters used for breweries by-products

Residue type	Residue output per 1 m^3 beer produced[25]		Methane yield potential[26]	Share accounted for biogas production
	tons of RM	tons of VS	$_{N}m^3CH_4/tVS$	% to residue output
Spent grain	0.328	0.0444	330	50

Sunflower oil production

Sunflower oil production accompanied by-products generation including husks, oil extraction cake (meal), sludge, formed during storage of unrefined oil, and soap stock. Extraction cake generated in the processes of the primary and the secondary seed wringing, and meal and soapstock created in the processes of oil extraction from primary wringing cake.

[22] Food Technology in the examples and problems [Text]: a textbook for university students / Tovazhnyansky L.L. [et al.]. - K. Centre of education books, 2008 - 576 p. (in Ukrainian).

[23] Vilis Dubrovskis, Imants Plume. Methane production from stillage // Engineering for rural development. - Jelgava, 24.-26.05.2017. – p. 431-436.

[24] Output industrial products, by type and regions in 2019. State Statistic Service of Ukraine, 2021

[25] Food Technology in the examples and problems [Text]: a textbook for university students / Tovazhnyansky L.L. [et al.]. - K. Centre of education books, 2008 - 576 p. (in Ukrainian).

[26] Aleksandra Szaja, et al. The effect of brewery spent grain application on biogas yields and kinetics in co-digestion with sewage sludge // https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7761201/

Consumption of raw materials for production of 1 ton of sunflower oil ranges from 2 tons (extraction method) to 2.1-2.2 tons (press method) of sunflower seeds. Specific husk generation is about 18 % by weight of sunflower seeds received for processing. After the first pressing 42% of the materials formed cake, which subsequently sent to the extraction. The total estimated oil yield is 44 % by weight of the processed seeds. Overall yield of residuals after extraction is some 35%. If the technology involves only pressing (first pressing), the main residual will be pressing cake, while its yield would be 0.96 tons per 1 t of sunflower oil.

Statistical data on production of unrefined and refined sunflower-seed oil[27] used for calculation biomethane potential from by-products using parameters in Table 1.6. Oil production in temporarily occupied territories of Ukraine was estimated using the specific rates of by-products formation per 1 ton of sunflower seeds (commodity crop production).

Table 1.6 – Parameters used for sunflower oil production by-products

Residue type	**Residue output per 1 ton crude sunflower oil produced**[28,29]		**Methane yield potential**[30,31]	**Share accounted for biogas production**
	tons of RM	tons of VS	$_{N}m^3CH_4/tVS$	% to residue output
Husk	0.398	0.3290	125	25
Extraction cake	0.773	0.6683	200	25
Unrefined oil sludge	0.008	0.0078	900	75
Soapstock*	0.055	0.0535	700	75

*Note: * - per 1 ton of refined oil*

Dairies

The main type of by-products in dairies, specifically in cheese production, is whey. Whey is a valuable product which processing enables its appliance in different food industries. Whey processing requires high-technology equipment installation and due to particular circumstances is not always reasonable. Thereby the treatment in biogas plants might considered as alternative form of its utilization. Whey generation in the production of curd, cheese and casein lies in the range of factor 1.86…5.25 per unit of product depending on the type of manufactured products[32].

Statistical data on production of hard, soft and brine cheeses[33] used for calculation biomethane potential from whey. For temporarily occupied territories of Ukraine level of production was estimated based on proportion of cattle livestock.

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[27] Output industrial products, by type and regions in 2019. State Statistic Service of Ukraine, 2021

[28] Consultant`s data

[29] http://eia.menr.gov.ua/uploads/documents/7302/reports/HpBPSktrWz.pdf

[30] Consultant`s data

[31] Anee Mohanty et al. A critical review on biogas production from edible and non-edible oil cakes // Biomass Conversion and Biorefinery. – 2021.

[32] Vasilyeva RA Production Accounting and Reporting for the dairy industry. Ulan-Ude Univ ESSTU, 2006. -170 p. (in Russian).

[33] Output industrial products, by type and regions in 2019. State Statistic Service of Ukraine, 2021

Table 1.7 - Parameters used for dairies by-products

Residue type	Residue output per 1 ton cheese produced		Methane yield potential[34]	Share accounted for biogas production
	tons of RM	tons of VS	$_{N}m^3CH_4/tVS$	% to residue output
Whey	3.5	0.2148	440	75

Wastewater sludge

The assessment of biogas production potential from sewage sludge covers only municipal wastewater treatment plants, for which there are statistical data on the passage of biological wastewater treatment. The data of the State Water Agency on the performance of public utilities in the field of sewerage in 2019 used as a basis. The overall wastewater volumes that are biologically treated at WWTPs in Donetsk and Luhansk regions, including temporarily occupied territories of Ukraine, were used from National report on the state of drinking water supply in Ukraine[35] on 2019 and in AR Crimea – the corresponding report on 2012.

In calculating the potential for biogas generation the average level of sewage sludge formation at the level of 1% to the volume of biologically treated wastewater taken. Specific CH_4 yield - 5.7 $_{N}m^3CH_4/t$ of raw sludge[36].

Organic fraction of municipal solid waste

To assess biogas production potential from municipal solid waste (MSW) the data of the Ministry of Communities and Territories Development of Ukraine regarding amount of MSW collected and landfilled in 2019 were used[37]. MSW volumes in temporarily occupied territories of Ukraine were accounted by using proportion in population numbers. The estimated current population in AR Crimea, taking into account[38], is 2.144 million.

Specific CH_4 yield from average Ukrainian MSW is 65.83 $_{N}m^3CH_4/t$ of raw MSW assessed by consultant based on the data of Ukraine's Greenhouse Gas Inventory 1990-2018[39].

It is assumed that availability of MSW for biogas production based on mechanical biological treatment is 75%.

[34] H Escalante et al. Anaerobic digestion of cheese whey: Energetic and nutritional potential for the dairy sector in developing countries // Waste Manag. – 2018. – vol. 71. – p. 711-718.

[35] https://www.minregion.gov.ua/wp-content/uploads/2020/12/naczionalna-dopovid-za-2019-rik.pdf

[36] Consultant`s data

[37] https://www.minregion.gov.ua/napryamki-diyalnosti/zhkh/terretory/stan-sfery-povodzhennya-z-pobutovymy-vidhodamy-v-ukrayini-za-2020-rik-2/

[38] https://uk.wikipedia.org (Населення України)

[39] https://mepr.gov.ua/files/docs/Zmina_klimaty/2020/Ukraine_NIR_2020%20draft.pdf

Biomethane production potential assessment

National level

The estimated biomethane potential from the most prospective feedstock types described above amounts to 9.73 billion m^3CH_4 a year, as on 2020 (Fig. 1.1).

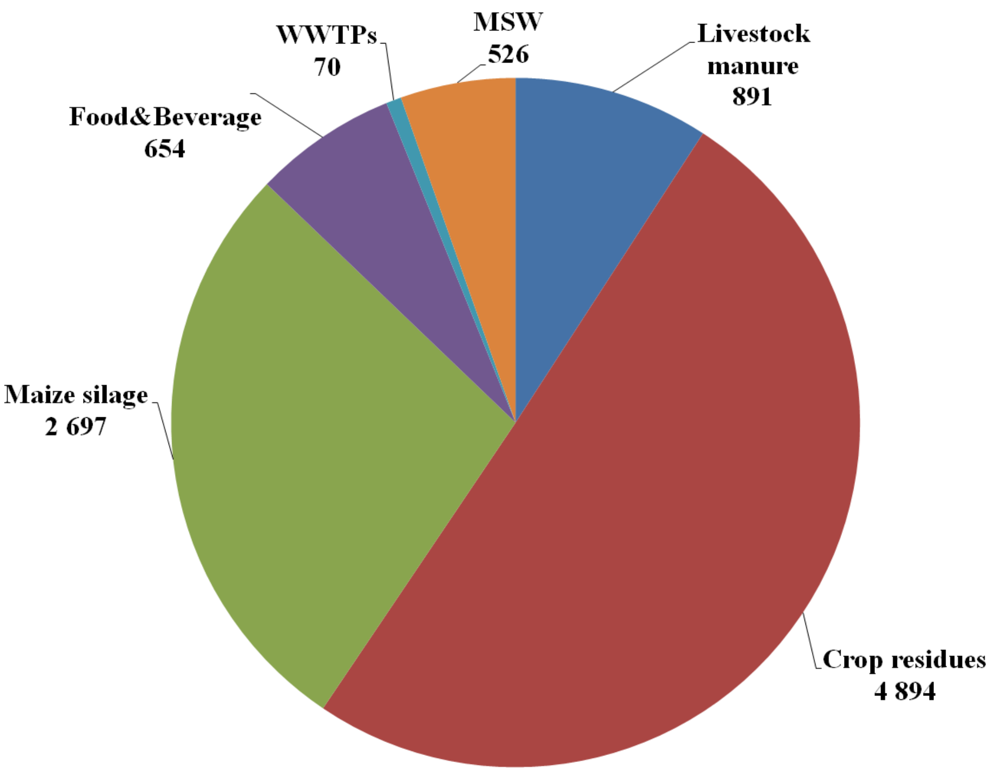


Fig. 1.1 - Biomethane potential in Ukraine by feedstock type, mln m^3CH_4 a year (2020)

Half of this potential is related to crop residues and one third to maize silage production. Animal husbandry wastes can contribute by 9.2%. Food&Beverage industry can contribute by 6.7%. Organic fraction of MSW and wastewater sludge could contribute together by additional 6.1%. The potential of biogas production from municipal sewage sludge amounts to only 69.6 mln m^3CH_4 per year. The overall potential related to temporarily occupied territories of Ukraine amounts to 467 mln m^3CH_4 per year or 4.8%.

In animal husbandry, the biggest share (53.5%) of biomethane production potential related to poultry litter and 30% to pig manure (Fig 1.2). Some 7.6% of this potential situated in TOT.

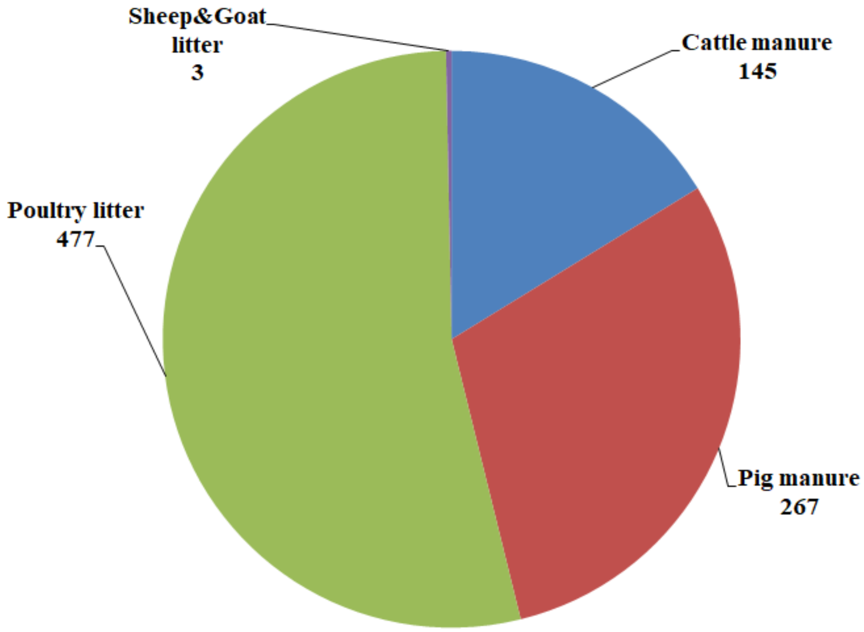


Fig. 1.2 - Biomethane potential by animal husbandry type, mln m^3CH_4 a year (2020)

The biggest biomethane potential among the crop residues could be obtained from wheat straw (34.7%) and maize stalks (34.7%) – all together 69.4% (Fig 1.3). Some 4.4% of this potential situated in TOT.

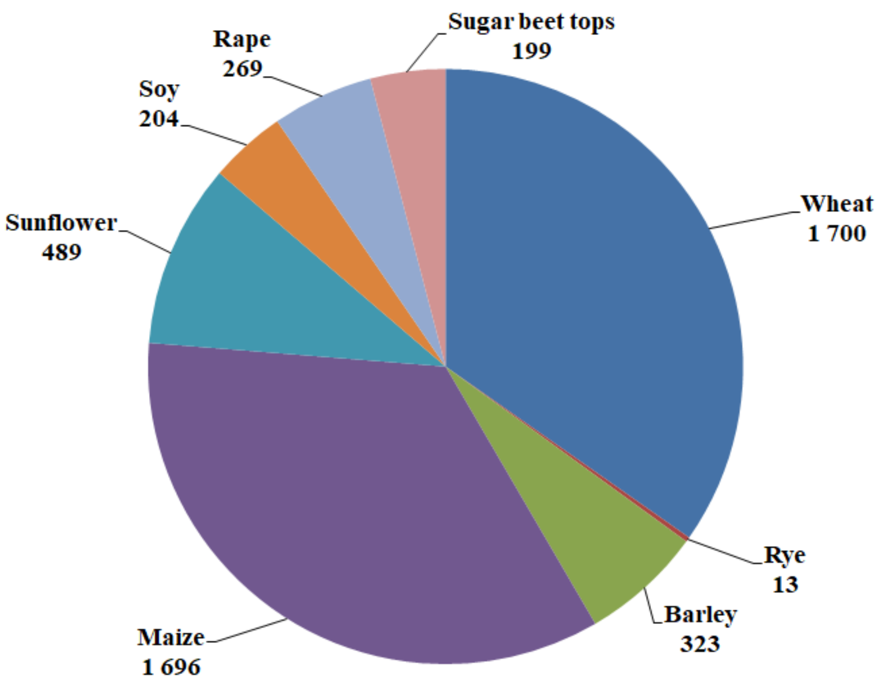


Fig. 1.3 - Biomethane potential by crop residues type, mln m^3CH_4 a year (2020)

The most valuable potential among food&beverage by-products belongs to sunflower oil industry and sugar production. The overall potential that oil by-products could contribute amounts to 0.32 billion m^3CH_4 a year, whereas oil press cake only can give 203 mln m^3CH_4 a year. Sugar beet press can contribute 205 mln m^3CH_4 a year. The rest accounted types of by-products amounts to the little shares, however in total can contribute up to 35% to food&beverage BMP potential. Estimated biomethane potential from food&beverage by-products related to TOT contribute only 0.4%.

Figure 1.4 shows estimated potential from different types of food&beverage by-products in more detail. Sunflower oil press cake, SBP, sunflower seed husks, stillage and cereal processing by-products are among the most contributing raw materials.

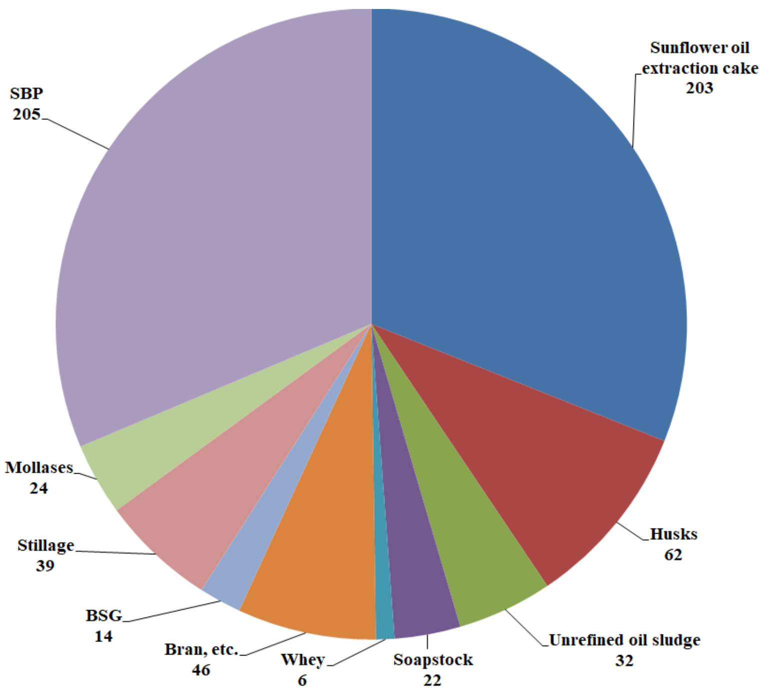


Fig. 1.4 - Biomethane potential by food&beverage by-product type, mln m^3CH_4 a year (2020)

Growing the required amount of maize silage with an average yield in Ukraine of 21.8 tons of green mass per 1 hectare, the required total land area is 1.221 mln hectares or 3.7% of the total arable land in Ukraine.

The estimated level of biomethane production potential for 2050 is more than 15 billion m^3 of CH_4/year. This estimate takes into account the possibility of increasing the production of poultry products by 10%, increasing production of major crops and food products by 30%, as well as the possibility of increasing biogas production from maize silage by 2.5 times by increasing land use for maize silage and crop yield growth.

Regional level

At the level of regions of Ukraine, almost a half of the potential for biomethane production is concentrated in 6 regions of Ukraine (Vinnytsia, Kyiv, Cherkasy, Poltava, Dnipropetrovsk, and Donetsk) (Table 1.8, Fig. 1.5). The highest potential estimated in Vinnytsya region, while the lowest in Zakarpattya region. The BMP by regions ranges from 38 to 846 mln m^3CH_4/year, averaged at 385 mln m^3CH_4/year by region.

Table 1.8 - Biomethane production potential by regions of Ukraine

Region	Biomethane potential, mln m^3CH_4/yr						
	TOTAL	Livestock manure	Crop residues	Maize silage	Food& Beverage	WWTPs	MSW
Ukraine	**9731,99**	**891,22**	**4893,57**	**2697,32**	**654,32**	**69,60**	**525,96**
AR Crimea	**193,55**	24,92	72,97	60,80	2,93	6,14	25,79
Vinnytsya	**846,15**	117,98	391,94	253,41	67,71	1,32	13,79
Volyn	**216,72**	30,28	75,97	87,01	7,42	0,36	15,68
Dnipropetrovsk	**567,16**	83,44	231,98	185,02	20,95	5,90	39,87
Donetsk	**560,48**	70,99	243,97	202,38	13,25	4,23	25,66
Zhytomyr	**300,06**	13,77	182,58	71,65	15,79	1,52	14,75
Zakarpattya	**37,68**	2,78	8,79	8,85	0,01	1,43	15,82
Zaporizhzhya	**332,18**	18,53	191,32	57,15	33,38	2,36	29,45
Ivano-Frankivsk	**144,83**	21,90	39,09	71,40	1,13	2,03	9,28
Kyiv	**792,24**	100,57	272,31	281,56	34,51	17,09	86,20
Kirovohrad	**410,45**	14,76	261,24	60,71	54,69	0,01	19,05
Luhansk	**320,22**	19,49	235,15	48,36	9,40	0,23	7,59
Lviv	**302,94**	36,38	112,04	99,11	17,52	4,81	33,09
Mikolayiv	**256,65**	5,65	175,07	25,32	39,98	0,11	10,52
Odesa	**336,64**	8,08	199,99	34,79	49,12	4,11	40,55
Poltava	**640,34**	40,39	349,04	193,75	40,25	2,12	14,79
Rivne	**166,05**	13,27	88,85	38,24	14,22	0,60	10,86
Sumy	**389,28**	17,62	272,58	86,58	3,80	0,03	8,66
Ternopil	**350,90**	26,72	187,94	93,13	28,38	0,93	13,81
Kharkiv	**477,13**	27,84	246,57	125,36	31,18	10,13	36,05
Kherson	**250,91**	20,53	156,61	52,82	11,27	1,19	8,49
Khmelnytskiy	**510,43**	36,86	290,30	130,40	34,70	1,61	16,55
Cherkasy	**680,67**	106,37	274,13	272,37	18,34	0,17	9,29
Chernivtsi	**67,07**	8,46	22,35	25,84	0,00	0,88	9,55
Chernihiv	**483,65**	23,65	310,78	131,30	6,79	0,30	10,82

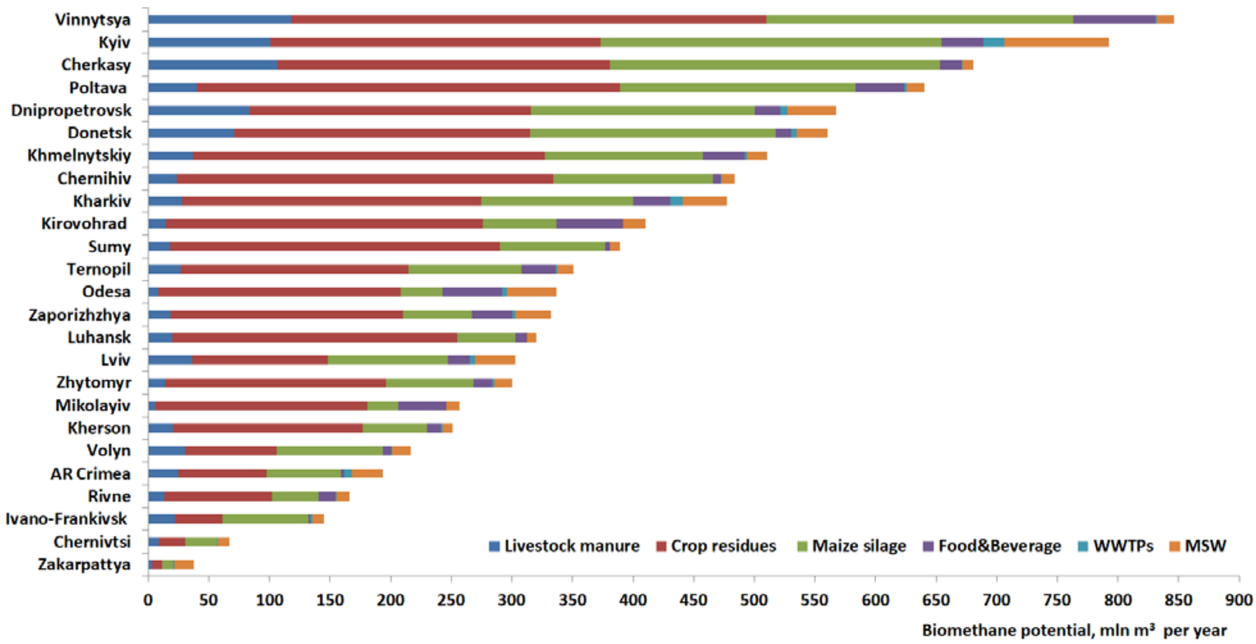


Fig. 1.5 - Biomethane potential by regions and by feedstock type, 2020

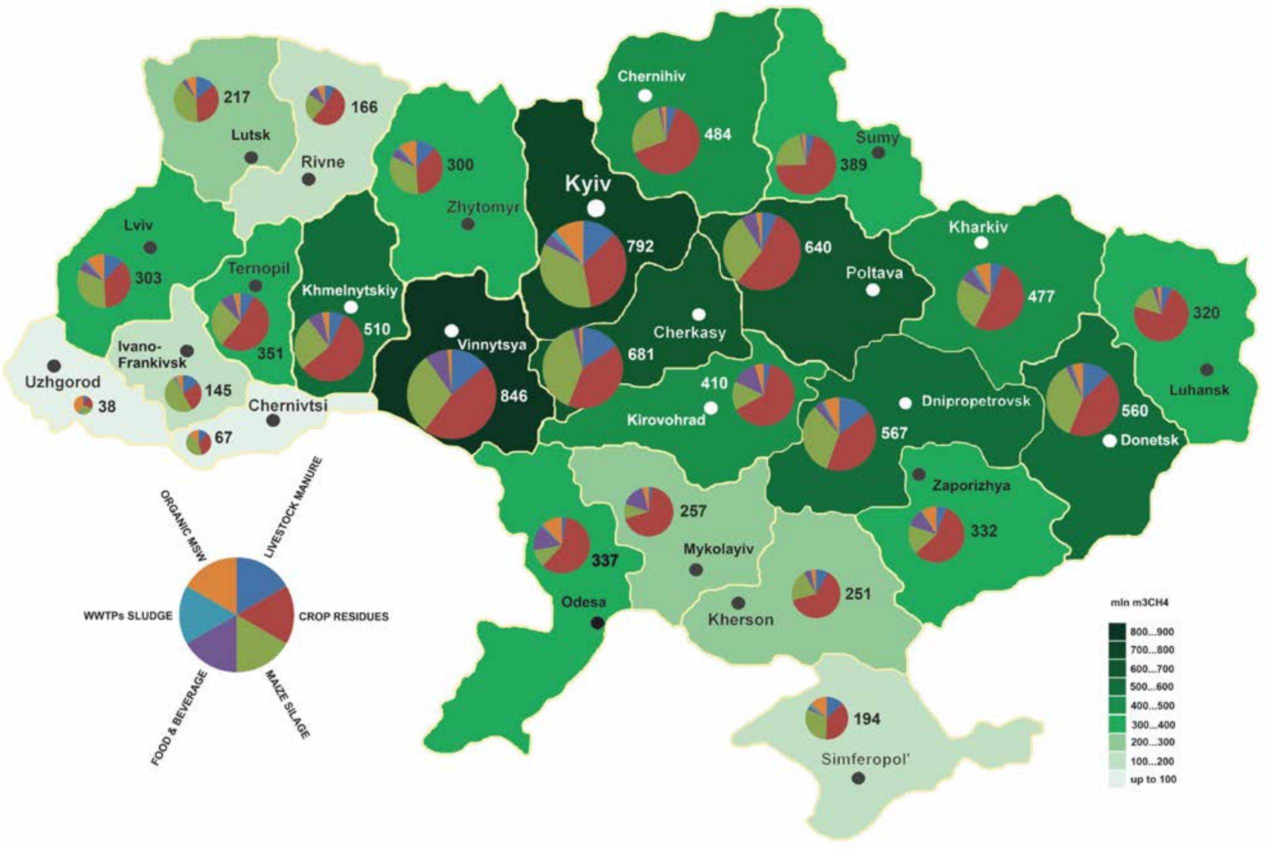


Fig. 1.6 – Mapping biomethane potential by regions and by feedstock type, mln m^3CH_4 a year, 2020

The estimated area needed for cultivation of demanded maize volumes for biogas production by regions given in Table 1.9.

Table 1.9 - Estimated area needed for cultivation of maize for biogas production

Region	**Average maize (as animal fodder) yield capacity in 2013-2016**	**Maize demand for biogas production**	**Area need for maize cultivation**
	tons per hectare	ths tons per year	ths hectares
UKRAINE	**21.8**	**25929.5**	**1192.1**
AR Crimea	10.0	584.5	58.5
Vinnytsya	25.4	2436.1	95.9
Volyn	27.1	836.5	30.9
Dnipropetrovsk	17.3	1778.6	102.5
Donetsk	16.3	1945.5	119.2
Zhytomyr	20.9	688.7	32.9
Zakarpattya	9.6	85.1	8.9
Zaporizhzhya	14.9	549.4	36.8
Ivano-Frankivsk	26.1	686.3	26.3
Kyiv	26.0	2706.7	104.0
Kirovohrad	20.4	583.6	28.6
Luhansk	15.1	464.9	30.8
Lviv	24.6	952.7	38.7
Mikolayiv	13.1	243.4	18.5
Odesa	10.3	334.5	32.4
Poltava	26.2	1862.5	71.0
Rivne	24.2	367.6	15.2
Sumy	31.2	832.3	26.6
Ternopil	31.3	895.3	28.6
Kharkiv	19.5	1205.1	61.9
Kherson	19.5	507.7	26.0
Khmelnytskiy	27.1	1253.6	46.2
Cherkasy	28.0	2618.4	93.4
Chernivtsi	23.3	248.4	10.7
Chernihiv	26.5	1262.2	47.7

District level

Data sources

The main data sources are data provided by the State Statistic Committee of Ukraine. With adoption Law of Ukraine "On State Statistics" it is unrealistic to obtain data sourced at the level of enterprises, districts or even regions.

Thus, where the only enterprise of a definite type is located within some territorial unit provided statistical data for this unit is pointed out as confidential. Data obtained by the Consultant from the Vinnytsia regional department of Ukrstat make it practically impossible to figure out the complete biomethane potential distribution at the districts level, especially for livestock enterprises.

Data on activity of food processing enterprises in Vinnytsia region were not provided at all. Data on poultry livestock number also were not provided since stated confidential, though the estimated methane generation potential from poultry litter is 84.5% to total livestock manure in the region. Data on other livestock number by districts are incomplete. For example, cattle number is not provided for 5 districts covering 96% to total cattle number in the region, pigs number – for 7 district covering 67% to total pig number, and sheep and goat number is provided only for one district (Table 1.10).

Data on crops production are mainly provided except rye and sugar beet (Table 1.11. Rye production in Vinnytsia region in 2020 took place only in 7 districts, data on production stated as confidential for all of them. Data on sugar beet production were provided partially.

Following administrative-territorial reform since 2021 there are only 6 districs in Vinnytsya region. Until 2021 there where 27 districts. Statistical data until 2021 were being provided for 27 districts. The occupied areas by 27 districts in Vinnytsia region averaged at 972 km^2 ranging from 590 to 1290 km^2.

Since 2021 it is envisaged the data will be more complete due to significant enlargement of territorial units within regions. However this will also considerably diminish fragmentation level.

Table 1.10 – Livestock number by 27 districts in Vinnytsia region (2020, end of the year)[40]

District	Livestock number, as of the end of 2020			
	Cattle		Pigs	Sheep and goats
	Total	incl. Cows		
Vinnytsia region	**76 791**	**29 831**	**100 936**	**3 123**
Bar	C	C	C	–
Bershad	2 007	690	16 600	C
Vinnytsia	1 908	664	7 652	C
Gaisyn	4 261	2 244	C	–
Zhmerynka	–	–	C	–
Illinets	4 664	2 207	2 850	C
Kalynivka	9 772	3 059	3 559	C
Kozyatyn	3 630	1 091	3 768	–
Kryzhopil	282	152	C	C
Lypovets	3 825	1 772	955	C
Lityn	4 149	1 774	2 234	–
Mohyliv-Podilsky	163	80	44	C
Murovanokurylovets	4 550	C	C	–
Nemyriv	462	203	C	C
Orativ	2 082	860	8 997	–
Pishchanka	C	C	C	C
Pohrebyshche	1 554	766	1 034	–
Teplytsia	914	379	8 143	–
Tyvriv	C	C	3 706	C
Tomashpil	4 785	2 248	–	–
Trostyanets	5 043	2 153	3 097	C
Tulchyn	748	C	1 153	294
Khmilnyky	7 421	2 755	C	–
Chernivtsi	C	C	–	C
Chechelnyk	C	C	C	–
Sharhorod	2 642	887	1 029	C
Yampil	8 873	3 165	2 764	C
Total number of districts where data listed as confidential	5	7	9	14
Share of livestock which is listed as confidential data	4%	9%	33%	91%

C – *stated as confidential data*

[40] Vinnytsia regional department of Ukrstat, 2021

Table 1.11 – The main crops production by districts in Vinnytsia region (2020)[41]

2020	Total, ths tons	Production in weight after finishing, ths tons							
		Wheat	Rye	Barley	Maize	Sunflower	Soy	Rape	Sugar beet
Vinnytsia region	**6 224,9**	**1 162,5**	**2,0**	**207,9**	**2 036,4**	**749,0**	**129,9**	**135,0**	**1 802,3**
Bar	170,3	36,3	C	6,2	80,1	29,4	6,3	12,0	C
Bershad	215,4	60,5	C	7,2	95,1	46,6	0,3	5,7	-
Vinnytsia	158,9	29,9	-	2,4	98,3	23,9	3,2	1,3	-
Gaisyn	141,3	54,0	C	2,9	58,8	18,8	6,1	0,7	C
Zhmerynka	207,9	55,4	-	3,9	95,6	42,4	3,4	7,2	-
Illinets	174,5	42,1	C	9,7	59,2	29,2	2,6	1,1	30,6
Kalynivka	260,2	46,8	-	10,7	117,7	32,2	20,9	1,3	30,6
Kozyatyn	354,4	57,8	-	18,7	122,0	28,7	7,4	7,2	112,5
Kryzhopil	110,9	33,0	-	3,4	52,5	14,7	6,8	0,6	C
Lypovets	202,8	44,8	-	6,9	104,7	33,3	7,8	5,3	C
Lityn	160,9	41,6	-	4,7	75,1	28,6	4,1	6,7	C
Mohyliv-Podilsky	107,6	29,1	-	4,7	42,9	22,5	0,6	7,8	-
Murovanokurylovets	116,9	25,8	C	12,3	39,1	28,6	1,6	9,6	C
Nemyriv	410,3	52,3	-	5,6	151,5	35,4	6,1	6,6	152,9
Orativ	178,5	45,1	-	13,1	65,4	36,9	3,3	1,1	13,5
Pishchanka	67,5	16,8	C	9,2	20,8	13,1	4,2	3,3	C
Pohrebyshche	224,3	52,2	-	11,7	74,6	33,6	5,3	2,3	44,8
Teplytsia	137,9	38,1	C	5,4	57,6	30,3	5,1	1,4	C
Tyvriv	176,4	47,2	-	6,7	89,6	26,5	2,2	4,2	-
Tomashpil	135,9	38,5	-	3,1	63,2	22,9	2,0	6,2	C
Trostyanets	144,4	59,3	-	8,8	40,8	26,2	2,3	6,9	C
Tulchyn	269,5	56,4	-	4,9	85,8	29,9	0,8	4,3	87,4
Khmilnyky	522,1	57,3	-	7,1	183,9	29,2	19,5	6,9	218,4
Chernivtsi	86,9	12,6	-	2,9	49,0	16,5	0,4	5,5	-
Chechelnyk	95,4	35,5	-	7,3	23,4	16,6	0,3	10,2	2,1
Sharhorod	178,6	59,7	C	13,8	58,7	35,3	3,9	7,2	C
Yampil	90,4	29,9	-	11,5	28,0	15,3	3,2	2,5	C
Total number of districts where data listed as confidential		0	8	0	0	0	0	0	11
Share of crop production which is listed as confidential data		0%	100%	1%	0%	0%	0%	0%	62%

Biomethane production potential

The following estimates of biomethane production potential by Vinnytsia region district are based on the assumptions and specific yields shown above for national level.

It should be noted that biomethane potential at district level in Vinnytsia region does not include the significant share of overall potential at region level related to poultry litter, maize silage, food&beverage byproducts, MSW organic wastes, WWTPs sludges – totally up to 40%.

The resulted biomethane production potential at district level in Vinnytsia region ranges from 3.7 to 35.6 mln m^3CH_4/yr (Figure 1.7). Khmilnyky, Kalynivka, Koziatyn, Nemyriv and Bershad districts are among the most contributing areas.

Taking into account area occupied by districts the estimated specific biomethane potential ranges from 6.1 to 28.5 thousand m^3CH_4/km^2/yr (Figure 1.8).The average delivery radius by districts is 17.5 km, with maximum 20.3 km. At least 3.7 mln m^3CH_4/yr could be provided from an area with an average delivery radius 13.8 km.

[41] Vinnytsia regional department of Ukrstat, 2021

Fairly each districts potential is related to two basic substrates – crop residues and maize silage. In this regional case poultry litter also could play a significant role in providing 99substrates for biogas production, at least 10% to total potential.

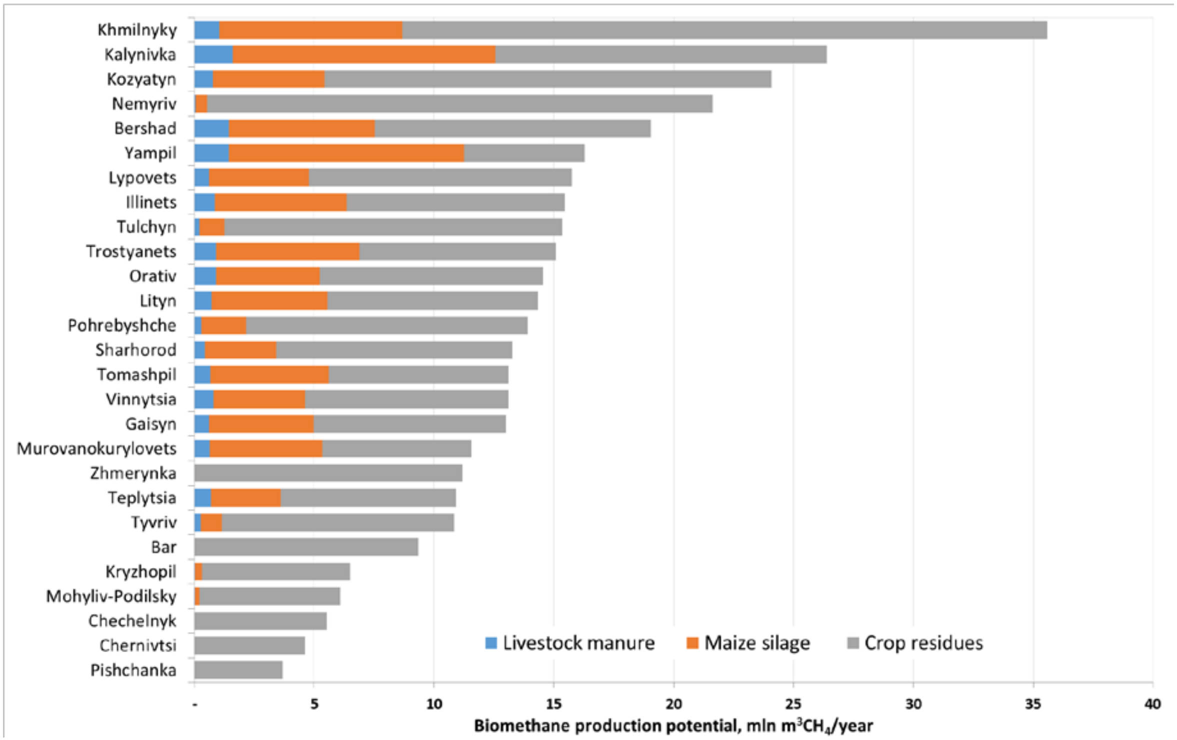


Fig. 1.7 – Biomethane production potential by districts in Vinnytsia region, as of 2020

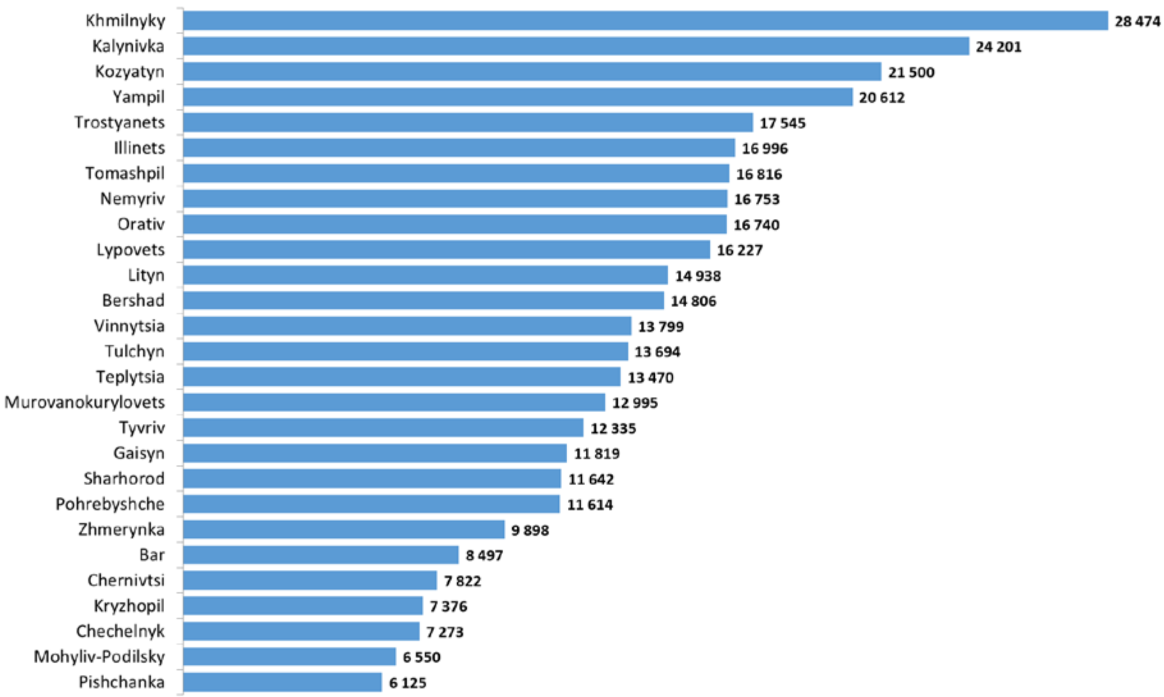


Fig. 1.8 – Specific biomethane production potential by districts in Vinnytsia region, $m^3CH_4/km^2/yr$

The main contributing crop residues to biomethane potential are wheat straw, maize stalks, sugar beet pulp and sugar beet tops (Figure 1.9).

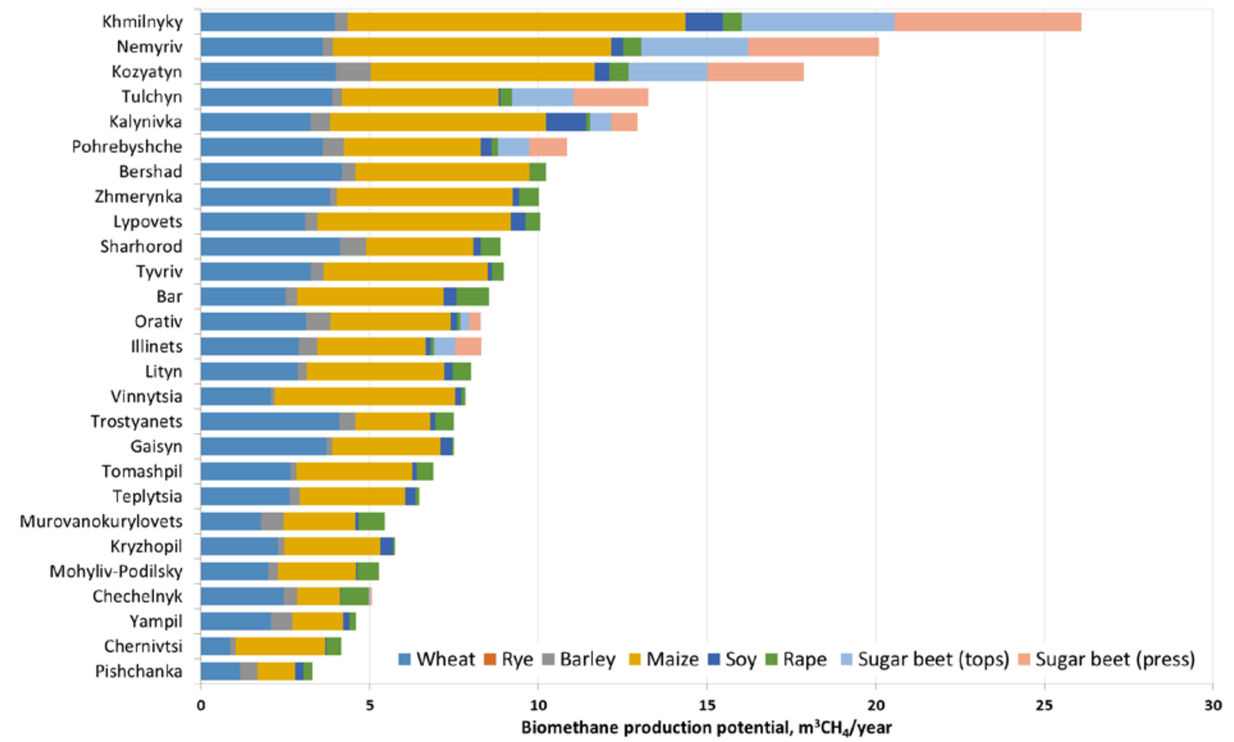


Fig. 1.9 – Biomethane production potential from crop residues by districts in Vinnytsia region, 2020

The results on biomethane assessment at district level in Vinnytsia region have shown that an average biomethane project with capacity starting from 4-5 mln m^3CH_4 could be realized within the area of an typical district in Ukraine with intensive agriculture activitities (according to the territorial division until 2020). In this case, the delivery radius would not exceed 15 km.

Biomethane production potential based on green hydrogen

Biomethane and green hydrogen roles, relation and comparison

The development of Ukrainian renewable electricity sector showed the substantial growth from 1.0 GWel in 2015 to 7.2 GWel in the end of 2020. Such development of RES installed capacity decrease the flexibility of Ukrainian power grid in terms of daily and seasonal power peaking balancing. Currently balancing is performed mainly by coal-fired large TPPs and gas CHPs, using some of the available units in hot reserve operational regimes to enable necessary response times (30 secs-15 minutes) on the grid operator request.

According to the official data of State Agency of Energy Efficiency and Energy Saving, the essential part of RES-to-grid electricity installed capacities for 2020 are solar PV (60%) and wind power (35%)[42]. The results of specific sectoral RES-to-power grid modelling for Ukraine[43] demonstrates that such tendency will be continued and the structure of RES-to-power grid supply with dominant role of solar PV and wind power will remain more or less the same till at least 2035.

From the other hand, the national grid operator (dispatcher) NPC "Ukrenergo" in its own comprehensive research[44] stipulates that "…present power grid balancing facilities (mainly large-scale coal-fired TPPs and at some extent large scale hydropower plants (HPPs) and hydro-accumulation power plants (HAPPs)) allows addition of installed capacity of non-stable RES-to-grid generation on the level of no more than 3 GWel".

The alternative approach for grid balancing could imply use of biomass/biogas CHP/TPP and utilization of renewable gases – biomethane, green hydrogen (hereinafter green hydrogen means any kind of hydrogen produced without application of non-renewable energy) and other renewable synthesis gases – either in existing grid connected gas-to-power installations or in the new ones built specially for balancing purpose. In this context, the biomethane and green hydrogen could be mutually transformed from one to another depending on the available transportation method and need of final consumer/technology.

Their utilization is not limited only in balancing, but could be practically used in any other applications in all sectors, where natural gas is currently used. From the other hand, several EU member-states already declared and some of them (Germany, for example) already approved the Renewable Gases Utilization Strategies, where their role in 100% renewable energy transition is

[42] Official data of SAEE: http://saee.gov.ua/uk/news/3287

[43] Transition of Ukrainian Energy Sector to 100% of RES till 2050. Issued by: Heinrich Boll Fund in Ukraine, Institute of Economics and Forecasting of NASU // O. Diachuk, M. Shepelev. R. Podolets, Yu. Oharenko at all. ISBN 978-617-7242-35-1. 2017. 90 pages.

https://ua.boell.org/sites/default/files/perehid_ukraini_na_vidnovlyuvanu_energetiku_do_2050_roku.pdf

Transition of Ukrainian energy sector towards 100% RES in 2050. International project ASET, NGO "REA", INFORSE-Europe // Oleksandra Tryboi, Alex Epik, Gunnar Boye Olsen et all. 2017. 101 pages.

http://rea.org.ua/images/projects/pdf/aset_report_rea_en_31082017.pdf

Transition towards a 100% Renewable Energy System by 2050 for Ukraine. Issued by Lappeenranta University of Technology // Michael Child, Dmitriy Bogdanov et. all. 2016.

http://www.neocarbonenergy.fi/wp-content/uploads/2016/02/3_Child.pdf

[44] Report of NPC "Ukrenergo" On Estimation of Necessity (Adequacy) of Generation Capacities, 2017.

https://ua.energy/wp-content/uploads/2017/10/Zvit-z-otsinky-vidpovidnosti-dostatnosti-generuyuchyh-potuzhnostej.pdf decisive. For example, Germany in its "Renewable Gases Strategy"[45] [46]stipulated that renewable gases are decisive in decarbonizing the energy sector till 2050 and, which is more important for Ukraine, own production of renewable gases in Germany is not sufficient to fulfill national targets on renewable energy even till 2030.

Consequently, the demand for green hydrogen and biomethane is being formed in the EU-28. Ukraine, having developed and currently under loaded natural gas transmission system (which could be used for renewable gases transportation) linked to the EU hubs, and large potential of feedstock for biomethane and green hydrogen production, can become potentially the large-scale exporter of the renewable gases to the EU-28 supplementing the internal use for balancing. The engagement of gas transmission system of Ukraine to renewable gases transportation is already foreseen, for example, in international project 2x40 GWel[47]. In this context, the special matter of interest is transformation of green hydrogen to biomethane, which could be used in existing gas transportation and storage infrastructure.

For Ukraine, biomethane could be seen as more suitable energy carrier in comparison with green hydrogen if considering full cycle value chain - feedstock availability, transportation, storage, reconversion on consumption site, combustion using existing infrastructure/ installations.

Table 1.12 - Comparison of hydrogen and biomethane energy density

Parameter	Hydrogen H_2	Biomethane CH_4	Ratio CH_4/H_2
Density, kg/m3 (0 ^{0}C, 1 bar)	0.087	0.716	**8.2**
NCV, **MJ/m3** (0 ^{0}C, 1 bar)	10.8	35.8	**3.3**
NCV of compressed gases for transmission pipeline conditions, **MJ/m3** (0 ^{0}C, 60 бар)	604	2484	**4.1**

It could be seen, that hydrogen has 8.2 times less density and 3-4 times less NCV (depending on conditions) comparing to biomethane. Consequently, if the green hydrogen could be converted to biomethane, this will be associated with reduction of all post-production costs proportionally to NCV and density.

The methanation reaction is already commercialized and could be for summarized by the equation:

$$CO_2 + 4H_2 \xrightarrow[\text{Ni, Rh, } Al_2O_3]{400\,^\circ C,\text{ pressure}} CH_4 + 2H_2O - 164 \text{ kJ/mol}$$

The process is already used on fossil-fuel-based industrial level installations (on existing oil-refineries, steel mills, chemical industries).

For the renewable gases, the hydrogen, as one of the necessary feedstock, is obtained from so-called "excess" renewable electricity – when the grid could not accept RES electricity due to balancing/regulation reasons – this electricity is used (also called as stored into) for hydrogen

[45] See, for example: https://www.handelsblatt.com/politik/deutschland/energiewende-nationale-wasserstoffstrategie-31-massnahmen-die-deutschland-zum-vorreiter-machen-sollen/25490610.html

[46] https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/die-nationale-wasserstoffstrategie.html

[47] https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf

production through electrolysis process. The CO_2, as another feedstock gas, could be obtained from the biogas-to-biomethane purification process (biogas typically consists of 50% biomethane (CH_4) and 40% carbon dioxide CO_2). The biomethane from biogas production usually does not imply CO_2 useful utilization. In proposed process it is utilized as feedstock gas for obtaining of additional portion of biomethane. Thus, proposed technical concept is combining the best features from two renewable gases – easily to obtained, relatively cheap, but hard and expensive for post-production stages (transportation and storage) green hydrogen from "excess" RES electricity transformed to more expensive on-site but much easier technically managed and cheaper for post-production stages biomethane.

The general scheme of the proposed technical concept is as follows:

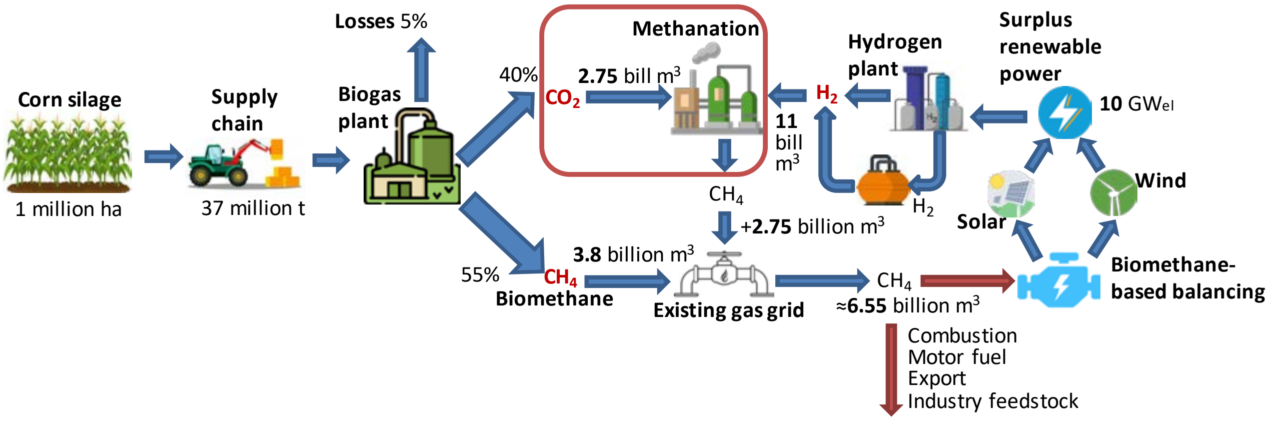


Fig. 1.10 - Principal scheme of methanation process using green hydrogen and CO2 from biomethane complex

The process on the initial stage includes production of biomethane on biogas complex with further supply of biomethane to the gas grid. Upgrading of biogas to biomethane separate CO_2 from biogas as additional by-product of the process. On the second stage the complex of hydrogen production installation (via utilization of RES electricity for H_2O electrolysis) produces hydrogen which is then utilized in methanation installation via methanation process as per chemical reaction with CO_2 obtained on first stage. Additional biomethane acquired in methanation process is then added to those biomethane obtained on the first stage from biogas purification. The gas balance of the process is the following: on 1 volumetric unit of initial biomethane there is 0.7 unit of volume of by-product CO2 generated as a result of purification process, and for 1 unit of volume of CO2, the 4 units of volume of H2 is needed for methanation process (with assumption of the chemical reaction ongoing with 100% efficiency, in practical conditions 100% reaction efficiency in non-achievable, usual indicator is 0.8-0.9). The reaction is exothermic, requiring heating of inlet products for more than 400 ^{0}C. Also, the utilization of high quality catalytic materials is needed to push the reaction balance towards CH4 production. This requires construction of complex with necessary infrastructure for heating, recycling of gases, recuperation of energy, providing flows of gases and their mixing with catalytic materials, etc.

The quantitative indicators provided on the scheme are based on the 2x40 GWel hydrogen production projects foreseen in the EU hydrogen strategy, one of them in Ukraine[48]. The respective amount of

[48] https://www.hydrogeneurope.eu/wp-content/uploads/2021/04/2021.04_HE_Hydrogen-Act_Final.pdf

hydrogen obtained from 40 GWel installed capacity of electrolysers working on the solar PV and wind electricity is assessed as 11.5 billion nm3/year. From the other hand, the left side of the diagram, the 1 mln ha of abandoned cropland may be used for maize harvesting for biomethane production in Ukraine representing 40-50% from total potential of biomethane. The resulting additional biomethane from methanation accounts as 2.75 billion nm3 out of 3.8 billion nm3 of initial biomethane from biogas upgrading (ratio 1 to 1.7 with assumption of "ideal" processes). The practical industrial ratio will be lower, closer to 1.4-1.5.

The biomethane with respect to energy cost in unit of mass/volume is more cost efficient in comparison with hydrogen. This influence on all next stages of transportation, storage, utilization, etc. The calculation shows that for 2021, the cost of energy contained in biomethane is 3 times lower that cost of energy contained in hydrogen. According to the forecast, the hydrogen energy cost will become lower and may possibly become comparable with biomethane energy cost in post-2050 period. That is why biomethane may be effectively used in the transition period 2021-2050.

Table 1.13 - Comparison of energy cost of biomethane and green hydrogen till 2070

Years	Units	**2021**	**2030**	**2050**	**2060-2070**
Assumed hydrogen costs[49]	$/kg	7	3	2	1
Cost of energy in hydrogen	$/MJ	0.058	0.025	0.017	0.008
Assumed biomethane costs	$/1000 nm3	700	650	600	500
Cost of energy in biomethane	$/MJ	0.020	0.018	0.017	0.014
Ratio Cost of energy in hydrogen / Cost of energy in biomethane		**3.0**	**1.4**	**1.0**	**0.6**

Mapping of biomethane from green hydrogen potential

The biomethane potential from methanation process dependents on total biomethane potential, distribution of RES potential and hydrogen production potential. Figure 1.11 illustrates the regional distribution of RES potential in Ukraine, which could be partly engaged for hydrogen production via electrolysis. Total potential is accounted as 2,700 billion kWh/year production, including ca. 2,300 billion kWh/year from solar PV and wind power (onshore and offshore).

[49] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

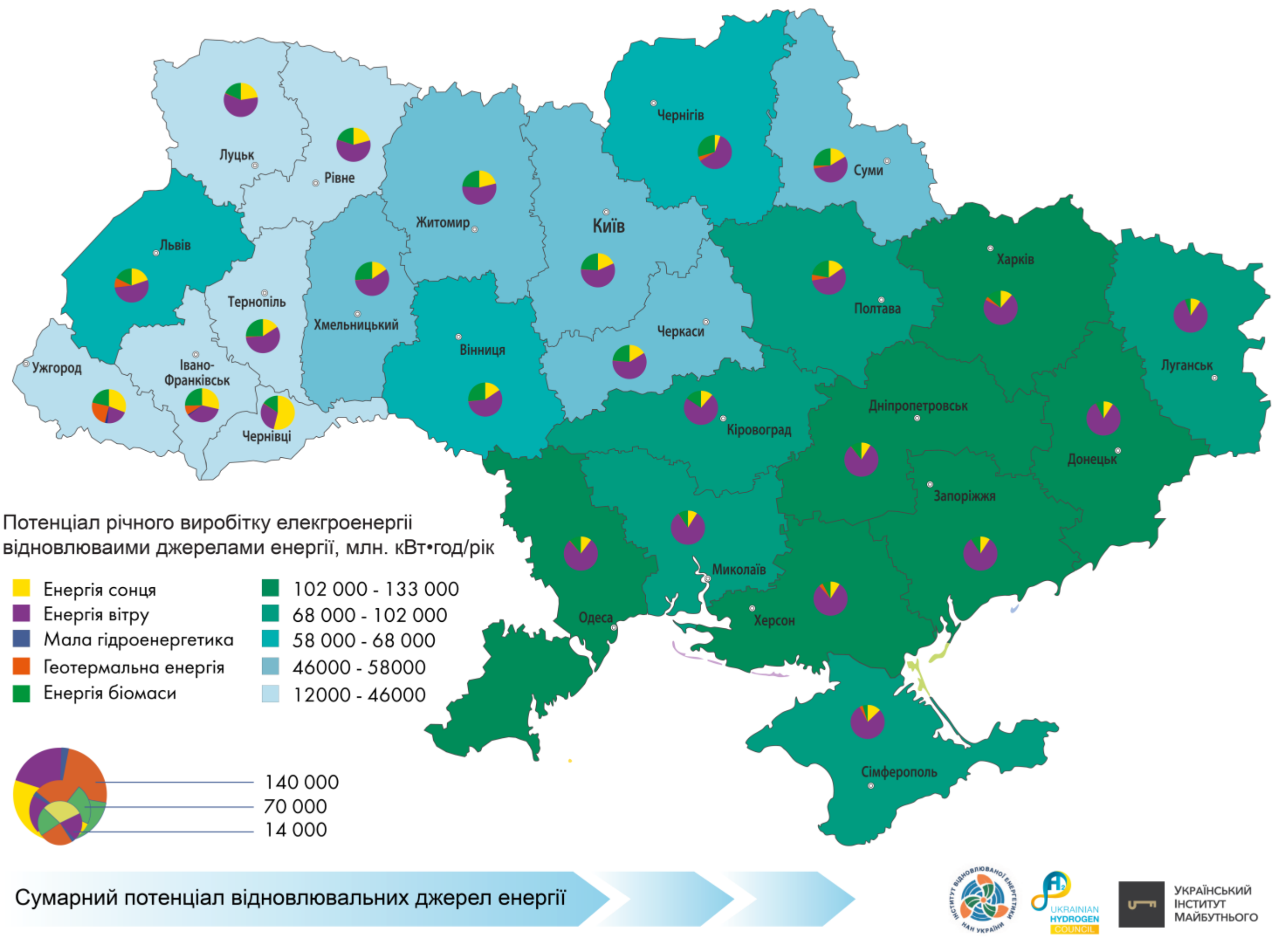


Fig. 1.11 - Mapping of RES potential in Ukraine[50]

Hydrogen production potential is presented on Fig. 1.12. This hydrogen potential may be partly used for methanation process to produce biomethane. The most of hydrogen potential is concentrated in Southern and Central Ukraine, the most biomethane potential is concentrated in Central and Western part of Ukraine. The superposition of two maps of regional potential distribution lead us to synthetic methane potential from methanation process. Total hydrogen potential is assessed as 505 billion nm3/year, out of which ca. 150-200 billion nm3/year may be considered as "produced from excess off-take RES-to-grid electricity" (solar PV and wind power).

[50] https://drive.google.com/file/d/11Ay1otLjiqIQelPKxSqfir2rYwGIKxSg/view

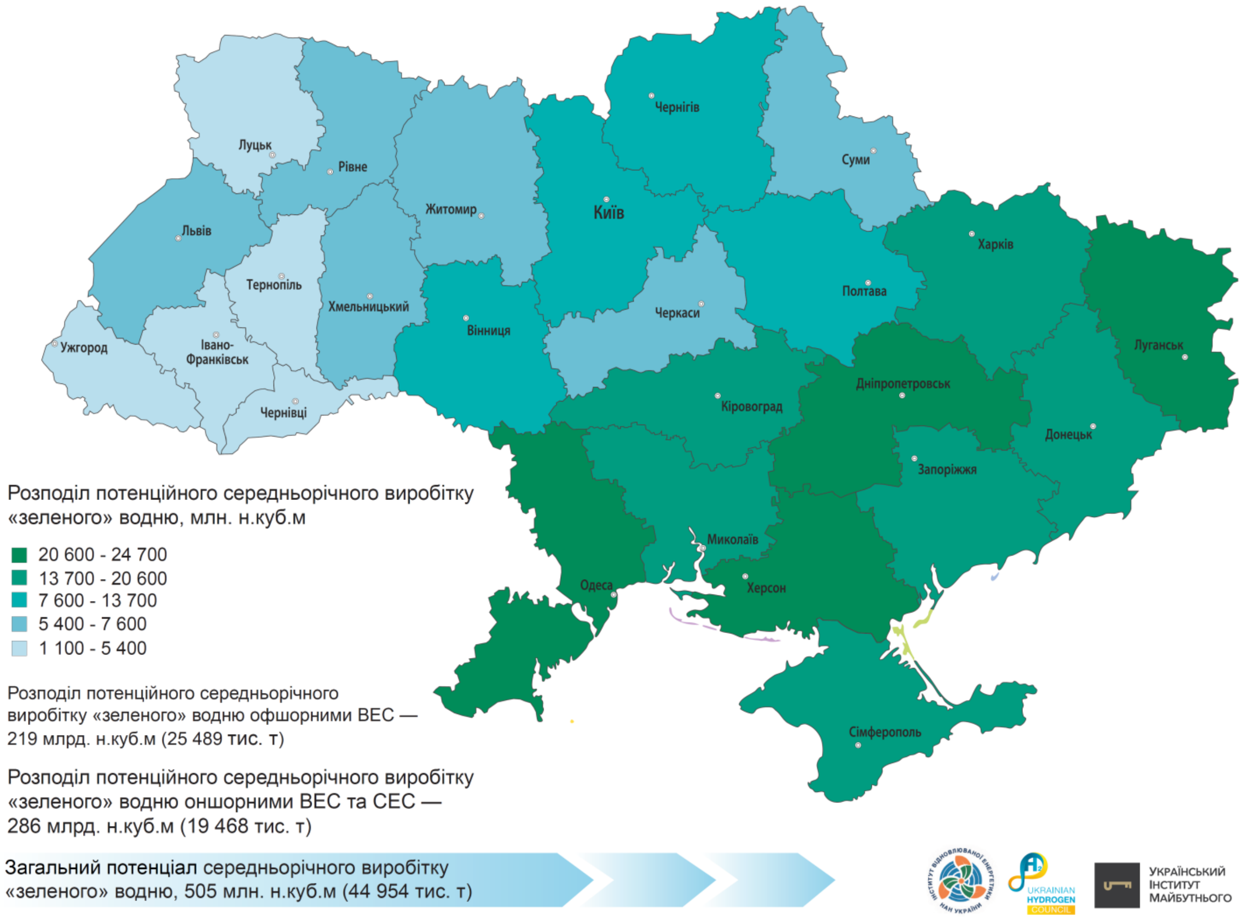


Fig. 1.12 - Mapping of hydrogen production potential (from RES) in Ukraine

In all regions of Ukraine, the hydrogen potential is 4-60 times higher than "theoretically needed" hydrogen for methanation on the basis of total biomethane potential in the region. The lowest ratio of available hydrogen/maximum needed for methanation hydrogen is for Kyiv region (3.8), the highest ratio – for Luhansk region (62). This means that hydrogen potential does not limit the generation of biomethane from methanation process even if all biomethane potential is used in region. The following table 1.14 summarizes the regional distribution of biomethane potential from methanation process.

Table 1.14 - Regional distribution of synthetic methane potential from methanation process

Region	CH4 potential, mln nm3/year	H_2 potential from PV and wind (max), mln nm3/year	H_2 needed fo methanation (max), mln nm3/year	CO_2 from biomethane upgrading, mln nm3/year	CH_4 potential by methanation, mln nm^3/year
UKRAINE	**8 286**	**286 391**	**27 551**	**6 888**	**4 351**
Crimea	0	14314	0	0	0
Vinnytsya	871	9055	2534	633	342
Volyn	214	5074	623	156	102
Dnipropetrovsk	603	24692	1754	439	306
Donetsk	353	20516	1027	257	183
Zhytomyr	295	7515	858	215	143

Region	CH4 potential, mln nm3/year	H_2 potential from PV and wind (max), mln nm3/year	H_2 needed fo methanation (max), mln nm3/year	CO_2 from biomethane upgrading, mln nm3/year	CH_4 potential by methanation, mln nm^3/year
Zakarpattya	37,7	1170	110	27	19
Zaporizhzhya	391	21029	1137	284	202
Ivano-Frankivsk	144	1968	419	105	62
Kyiv	802	8263	2333	583	314
Kirovohrad	485	13711	1411	353	237
Luhansk	139	20646	404	101	74
Lviv	298	5637	867	217	138
Mykolaiv	335	19032	975	244	173
Odesa	431	22173	1254	313	222
Poltava	658	9818	1914	479	289
Rivne	161	5409	468	117	80
Sumy	394	7570	1146	287	182
Ternopil	340	4721	989	247	147
Kharkiv	513	17517	1492	373	256
Kherson	269,5	22021	784	196	142
Khmelnytskiy	498	7051	1449	362	216
Cherkasy	686,5	7138	1997	499	270
Chernivtsi	67	1753	195	49	32
Chernihiv	485	8598	1411	353	221

The volume of biomethane from methanation is mainly dependent on CO_2 quantity acquired as by-product of biogas upgrading. Then, the factor of non-uniform distribution of RES and hydrogen potential is used for normalizing the resulting potential. For those regions where the hydrogen/RES potential is lower, the conservativeness factor for biomethane from methanation potential is applied. The efficiency of the whole methanation process is taken as 0.7, and the resulting ratio of biomethane potential/biomethane from methanation potential is 2/1 (i.e. each volume unit of biomethane gives additional 0.5 volume unit of biomethane via methanation process).

The highest potential of synthetic methane from methanation is for Vynnystya, Poltava, Dnipro, Kyiv regions (the same as for conventional biomethane potential). For the regions such as Ivano-Frankivsk, Chernivtsi, Zakarpattya, Luhansk the potential is not only the lowest among all other regions, but is close to capacity of a typical single-unit biomethane methanation complex, so consideration of this regions for biomethane production through methanation is questionable.

Reversed methanation (production of hydrogen from biomethane, based on available technologies)

The biomethane and biogas could be also converted to hydrogen by reverse methanation reaction on the site where the hydrogen is needed for specific production purposes. In this case, three options may be applicable – first one is direct production of green hydrogen on biogas/biomethane complex adjacent to or integrated in the hydrogen consumer site, second one – direct production of hydrogen and biomethane on biogas complex and pumping the technical mix of 5-10 vol% green hydrogen with NG/biomethane to the gas transmission network, third option – production of biomethane, pumping to the gas transmission network, and then performance of reverse methanation process on the industrial sites of hydrogen consumers connected to gas grid (and far from biomethane complex).

In first case, the existing grids and infrastructure of hydrogen consumer may be used for transportation, storage, conversion, and other technical operations between production and consumption, however biogas/biomethane complex has to be located close to such consumers, which limits the potential suitable sites locations.

In second case, the biogas complex is not linked to the consumer, however the transportation costs will be additional, also the storage facilities and conversion facilities for green hydrogen treatment has to be added on biogas/biomethane complex.

The third case includes performance of same process two times – at first methanation to convert hard to transport hydrogen to easier to transport biomethane and then reversed process – extraction of hydrogen from biomethane on the site of consumption. This could be viable option however in comparison with supply of direct mix of hydrogen and biomethane/NG (which is technically possible), the additional process will increase the costs for hydrogen extraction.

In case of production of only green hydrogen on biomethane complex (or RES electricity electrolysis complex), the output green hydrogen quantities may be pumped to the specially redesigned hydrogen transportation grid (more than 10 vol% mix with methane/biomethane). This option is assessed currently as non-viable, as this will require significant costs to grid reconstruction (or construction of new hydrogen grids in case of only-hydrogen transmission, as existing gas grids shall perform also the main function – supply of NG to consumers, which will be not possible in case of 100% hydrogen pumping). In comparison with green hydrogen mix with biomethane/NG, this option is much more costly, as it will require additional transportation/storage/treatment infrastructure for the gas with lower energy density than biomethane (see explanations above).

The technology of reversed methanation is commercialized and used in most of the industrial applications where hydrogen is needed (for example, oil refineries, steel mills (redox hydrogen), chemical plants (hydrogenation processes), plastics production, cement plants, paper mills, glass production, etc.). The essence of the application of reversed methanation technology based on biomethane is the same as those based on natural gas of other fossil fuels.

On practice, the most suitable solution is seen in the combinations of all mentioned options, when biogas complex is connected with methanation complex and hydrogen production complex (all of them located within one site of adjacent to each other), so such combined installation could basically produce two products – green hydrogen from biogas (reversed methanation) and RES electricity (electrolysis) and biomethane from green hydrogen (direct methanation) depending on the demand of consumption side, mixing requirements of local NG grid, technical capacity of the grid or on-site consumption. Such scheme could compensate the local /seasonal consumption fluctuations for both green hydrogen and biomethane (and RES offtake electricity, which is not always available) and make the biomethanation complex more flexible. In this case, the connection to the transmission or distribution gas network is needed (more preferably transmission) with application of boosting compressor station.

As the methanation reaction is reversed, depending on conditions, temperature and catalytic materials applied, if we take as a base that 10% (practical technically suitable mix for transportation in NG transmission networks) of biomethane potential will be taken out to produce only hydrogen via reversed methanation (and 90% - for direct methanation), then the hydrogen potential will be 2.8 billion nm3/year (ca. 1 % from max hydrogen potential from solar PV and wind and up to 3-5% from hydrogen potential produced from "offtake" RES electricity only) only from biomethane reversed methanation. If all 100% biomethane potential will be applied for reversed methanation process to produce green hydrogen, then the hydrogen potential will be ca. 28 billion nm3/year.

The respective costs associated with all mentioned options linked to the concrete decisions (configurations of facilities and equipment) would be estimated in the next sections.

Potential biomethane producers with capacity above 1000 m3/hour of biomethane

Feedstock demand for biomethane plant of capacity 1000 m^3/hour

To produce 1000 m^3/h commercial biomethane with a CH_4 content of 97%, a volume of biogas with an equivalent CH_4 content of 1100-1150 m^3/h has to be produced at the biogas plant, which takes into account the biogas consumption for heating bioreactors and technological losses of CH_4 during biogas upgrading (1-2% depending on the upgrading technology). In order to analyze the possibilities of consolidating from smaller projects, potential biogas/biomethane plants of lower capacity starting with 300 m^3/h also considered.

As a rule, biogas projects and accordingly biomethane projects are constructed at the facilities generated basic types of raw materials as soon as their transportation less cost-effective/expedient among the existing alternatives. It usually includes livestock enterprises, sugar factories, wastewater treatment plants. Sources of significant raw materials can also be food&beverage enterprises (breweries, distilleries, flour&cereals mills, oil extraction plants, dairy plants). In addition to the basic types of raw materials additional types are also used among which the most common in Ukraine is maize silage.

Cattle farms

The production of 1000 m^3/h of biomethane will require 1309 t/day of cattle manure, which could be available at a farm with an average permanent livestock of more than 72 thousand heads.

It should be noted that there are no cattle farms of such size in Ukraine. The largest cattle farm (as of 2008), with a total population of about 26,000 heads, was the Druzhba Narodiv farm in the Autonomous Republic of Crimea.

Thus, cattle farms can only be basic facilities that will need additional raw materials. If 1.5 parts of maize silage (MS) or 0.66 parts of wheat straw (WS) are added to cattle manure (by raw weight), biomethane projects with a capacity of 1000 m^3/h of biomethane will be possible to implement with an average cattle population of 8.6 thousand heads. In this case up to 90% of the total volume of methane would be produced from maize silage (or straw).

Based on the available data from web-site[51] milkua.info we recognized 25 cattle farms where biomethane project with capacity above 300 m^3/h of biomethane could be implemented with the use of manure and additional raw materials (Annexes, Table A1-1). Given the additional raw materials for biogas production, farms with 2,500 heads may be potentially attractive in terms of cattle farms. From these, only one potential project with a capacity above 1000 m^3/h of biomethane could be implemented.

There are 4 large cattle farms in Poltava region, 3 large farms in Cherkasy and Chernihiv regions each, 2 farms – in Ternopil region, and 1 farm in each of the rest 13 regions of Ukraine.

Pig farms

The production of 1000 m^3/h of biomethane will require 608 t/day of pig manure, which can be formed on a farm with an average permanent livestock of more than 143,000 heads.

There are no separate pig farms with such livestock in Ukraine, but there are a number of large complexes that unite a group of pig farms located in a certain region. For example, the largest such complex in Ukraine is the pig farm APK Invest in Donetsk region, where the total livestock is more than 320,000 heads. A joint venture company Niva Pereyaslavshchyny in Kyiv region holds a total of more than 240,000 head on 12 separate production sites. In Ivano-Frankivsk region, the largest pork producer is the Ukrainian-Danish enterprise Goodvalley, where a total of 195,000 pigs are kept on 7 separate pig farms. Until recently, one of the largest pig farms in Ukraine was Kalyta Agro-Industrial Complex in the Kyiv region, the capacity of which allowed to keep more than 70,000 pigs. This complex, in contrast to the vast majority of other pig farms in Ukraine, has its own treatment facilities for aerobic stabilization of manure. Information on the current performance of the plant in the public domain could not be found there[52].

If 3 parts of maize silage or 1.33 parts of wheat straw (by raw weight) are added to pig manure, biomethane projects with a capacity of 1000 m^3/h of biomethane will be possible to implement with an average pig population of 18,000 heads. Up to 90% of the total volume of methane would be produced from maize silage (straw).

Table A2 shows the 49 largest companies and individual pig farms in Ukraine as of 2020-2021, which could implement the production of biomethane with a capacity of 300 m^3/h with the addition of plant co-substrates. The companies listed in the table keep more than 2.2 million pigs at the same time, which is 60% of the total available livestock on January 1, 2021.

Poultry farms

The production of 1000 m^3/h of biomethane will require 260 t/day of chicken manure, which can be formed on a farm with an average permanent livestock of more than 2.6 million heads.

Recently, the largest poultries in Ukraine are Vinnytsia poultry of agricultural holding MHP, Agromars complex, Agro-Oven poultries, Dniprovskiy poultry farm, Volodymyr-Volynsky poultry farm. For example, Vinnytsia poultry farm holds at the same time up to 40 million head of chickens on 3 production departments in close vicinity to Ladyzhyn city.

[51] http://milkua.info/uk/post/section/ukrainian-farms
[52] http://www.akkalita.com.ua/aboutus.html

If 1.5 parts of maize silage or 0.66 parts of wheat straw (by raw weight) are added to the manure, biomethane projects with a capacity of 1000 m^3/h of biomethane will be possible to implement with an average poultry population of a million heads. At the same time, up to 60% of the total volume of methane will be produced from maize silage (straw).

In table A3 14 the biggest poultry farms/complexes in Ukraine are listed based on available data from open sources [53, 54, 55, 56, 57, 58, 59, 60, 61].

Sugar plants

The production of 1000 m^3/h of biomethane will require 790 t/day of sugar beet pulp (with uniform consumption throughout the year). This amount of SBP, taking into account the share of its use for biogas at the level of 75%, can be formed at a sugar factory with a processing capacity of 5 thousand tons of sugar beet per day. At simultaneous use of 75% of the formed molasses, the capacity of plant from 4 thousand tons a day on beets will be sufficient.

There are 18 sugar factories in Ukraine with a capacity of 4 to 8 thousand tons sugar beet per day. The largest plants with a productivity of 8 thousand tons/day of beets are 2 plants of Radekhivtsukor in Chortkiv and Radekhiv. and Kryzhopil sugar plant of PJSC "Food Company" Podillya ".

According to the National Association of Sugar Producers of Ukraine "Ukrtsukor" in the season 2020/2021 in total 30 sugar factories were under operation including 13 plants from the list in the table A4 (2 plants did not work: Gorokhivsky for Zasilsky sugar factories).

Sunflower oil mills

The production of 1000 m^3/h of biomethane will require 160 t/day of sunflower meal/cake, or 267 t/day of sunflower husk, or 40 and 30 t/day of soapstock and unrefined oil sludge, respectively.

Given the simultaneous use of 75% of all by-products of oil extraction plants for biogas production, the required amount of 1000 m^3/day of biomethane can be produced at the plant with a capacity of more than 126 tons/day of oil or 46 thousand tons/year. In total 15 enterprises could meet this criterion. The largest oil extraction plant is OJSC "Kirovogradolia" with a production capacity of 178.5 thousand tons/year of sunflower oil. The largest potential biomethane projects based on oil extraction plants shown in Table A5.

Distilleries

[53] https://ptichki.net/katalog

[54] http://www.agromars.com/company/vertical-integration/

[55] https://latifundist.com/novosti/56012-ovostar-yunion-uvelichil-obem-proizvodstva-yaits-za-6-mesyatsev-2021-g

[56] https://agrotimes.ua/elevator/volodimir-volinska-ptahofabrika-zbilshit-pogolivya-kurej-yakih-viroshchuyut-bez-antibiotikiv-do-50/

[57] https://latifundist.com/spetsproekt/684-starinskaya-ptitsefabrika-20-letiyu-kompanii-posvyashchaetsya

[58] https://latifundist.com/kompanii/21-dianovskaya-ptitsefabrika

[59] http://agro-business.com.ua/agrobusiness/item/3745-u-volynskii-oblasti-bulo-zapushcheno-potuzhnu-ptakhofermu.html

[60] https://latifundist.com/istorii-uspeha/snyatinskaya-ptitsefabrika-bez-kompromissov-kogda-rech-idet-o-bezopasnosti-i-kachestve

[61] https://latifundist.com/reportazhy/124-ptitsekompleks-morozovka-agro-kak-ocherednoj-vitok-razvitiya-novaagro

The production of 1000 m^3/h of biomethane will require more than 1000 m^3/day of stillage, which can be formed at distilleries with a capacity of almost 40 thousand tons of spirit per year. None of the existing distilleries in Ukraine would have enough stillage to produce 1000 m^3/h of biomethane.

In recent years, the activity of distilleries in Ukraine has been under the influence of demonopolization process, as a result of which the capacity of the state enterprise Ukrspirit has been put up for sale. Ukrspirit (41 production sites throughout Ukraine) can produce more than 36 million decalitres per year. The largest distilleries in Ukraine listed in the annexes (Table A1-6).

Breweries

The production of 1000 m^3/h of commercial biomethane will require more than 600 t/day of beer`s spent grains, which can be formed in breweries with a capacity of almost 70 million decalitres of beer per year. In fact, such a condition can be satisfied only by Obolon Brewery CJSC in Kyiv. Table A7 shows the largest breweries by production capacities in Ukraine.

Dairies

The production of 1000 m^3/h of biomethane will require more than 1000 m^3/day of whey, which can be formed in cheese factories with a capacity of more than 106 thousand tons of cheese per year. In 2008, the highest productivity was the Pyriatyn cheese factory - almost 16 thousand tons per year. Thus, cheese factories can be considered as not promising in terms of the availability of raw materials for the production of biomethane of sufficient capacity.

Flour&Cereals mills

The production of 1000 m^3/h of biomethane will require more than about 100 t/day of by-products of flour production and grain processing, which can be formed at flour mills with a production capacity of more than 70 thousand tons of various products.

The 10 largest flour mills in Ukraine[62], which cover 45% of this market, include:

1. Vinnytsia KHP
2. Novopokrovsky KHP
3. Dnipromlyn
4. Capital Mlyn
5. KPF Roma
6. Ukrainian flour milling company
7. Khmelnitsk-Mlyn
8. State Enterprise Kulindorovskiy KHP
9. Krolevetsky agrokombinat of bread products
10. Vinnytsia-Mlyn

Maize silage production

The production of 1000 m^3/h of biomethane will require about 265 t/day (96,840 t/year) of maize silage. Growing this amount of maize with an average yield of 21.8 t/ha will require 4440 ha of land. With an average annual density of land plots under maize cropping around the biomethane plant of 0.5, which takes into account the need for crop rotations, cultivation of other crops, the availability

[62] https://latifundist.com/rating/top-10-proizvoditelej-muki-2017

of non-agricultural land, the average radius of collection/delivery of silage to the biogas plant will be 5.5 km.

Crop production

Table 1.15 shows the estimated data on the required area and radius for collection of crop residues to ensure the productivity of the biomethane plant 1000 m^3/h of biomethane.

Table 1.15 – Area and distance needed for crop residues collection for 1000 m^3/h biomethane plant

№	Crop	Biomethane production potential, m^{3}CH$_4$/t commodity crop	Needed production capacity of an enterprise, t/year	Crop production capacity (average Ukraine), t/ha	Cropping density, %	Area needed for crop cultivation, ha	Average radius of raw material collection and delivery, km
1	Wheat	230,40	43 724	4,34	0,75	22 388	8,44
2	Rye	230,40	43 724	3,10	0,75	31 343	9,99
3	Barley	184,32	43 724	3,70	0,75	26 261	9,15
4	Maize	181,35	72 215	7,77	0,75	17 703	7,51
5	Sunflower	101,46	188 652	2,70	0,75	139 047	21,04
6	Soy	191,25	52 675	2,33	0,75	43 061	11,71
7	Rape	270,00	74 622	2,57	0,75	55 306	13,27
8	Sugar beet (tops)	6,43	261 832	47,03	0,75	8 248	5,13

Wastewater treatment plants

Only two municipal wastewater treatment plants in Ukraine can provide sufficient sludge amount to a biomethane plant with a capacity of more than 1000 m^3/h of biomethane. These are Kyivvodokal's treatment facilities in the village of Bortnychi, Kyiv region (1.7 thousand m^3/h of biomethane) and treatment facilities in Kharkiv – both Bezliudiv and Dykaniv treatment facilities, together about 1 thousand m^3/h of biomethane.

Municipal solid wastes treatment

The introduction of green tariff for electricity produced from biogas and landfill gas led to the fact that a significant part of the energy potential of landfill biogas (LFG) in Ukraine has already been implemented by private companies. LFG is used for electricity production only. There were almost 30 MW$_{el}$ of total installed capacity at 26 Ukrainian landfills and waste dumps in 2020.

The total potential of existing Ukrainian landfills is evaluated as 40-50 MW in term of installed electrical capacity (equivalent of 10 000 – 12 500 mln m^3/h of biomethane).

In 2020 the biggest amount of electricity was produced at Zaporizhzhya landfill (14.2 GWh – equivalent of 400 m^3/h of biomethane) and Kyiv landfill #5 (8.9 GWh – equivalent of 250 m^3/h of biomethane)[63]. Currently biggest Ukrainian LFG project started in November 2020 at Odesa landfill produced 2 GWh of electricity per month (equivalent of 700 m^3/h of biomethane).)

In the near future we can expect the start of new big project in Lviv, increasing the capacity of the project in Kiev as well as the implementation of projects in some medium-sized cities of Ukraine. However, in general, the potential for biogas collection at landfills has been already implemented. Prospects for methane production from solid waste are mainly related to the construction of regional MSW treatment centers in the process of implementing the waste management strategy until 2030 adopted in 2017. We can expect the construction of several dozens of MSW treatment complexes involving mechanical and biological processing of solid waste with the production of biogas and biomethane with a capacity of 100,000 tons of solid waste per year or more based on new administrative-territorial structure of Ukraine (cluster approach). The complex with a capacity of 100,000 tons of MSW can theoretically produce up to 700 m^3/hr of biomethane.

In spite of the fact that technologies of mechanical biological treatment of waste with biogas production will probably be developed in future, a certain part of LFG potential may be related to the construction of regional sanitary landfills in the framework of waste management strategy by 2030 and further. The role of landfilling will remain significant in Ukraine for at least several decades. The concentration of waste resources on large scale and strict compliance with operation rules for sanitary landfills would allow recovering up to 75...85% of the generated LFG even total amount of LFG will be reduced due to avoiding direct landfilling of biodegradable waste.

As a rule such regional sanitary landfills will be coupled with waste treatment centres what provide opportunities for large scale biomethane production.

Possibility of creating value chains related to biomethane generation and use around specific priority areas/territories

Biomethane by biogas upgrading

Value chains of biomethane supply in the gas networks have two main components, namely: a) component of biomethane production; b) component of biomethane supply to the consumer. Both components are variable. The main schemes of the biomethane value chains are shown in Fig. 1.13-1.16.

Regarding the supply of biomethane, the main opportunities in the value chain include its supply to gas networks (low and medium pressure gas distribution networks, high pressure gas transmission networks) with subsequent consumption by the end consumer. One of the possible options for alternative use of biomethane may be the direct use of its compressed or liquefied form on transport (agricultural machinery, public transport, passenger transport, shipping and air transport). This option may be appropriate if the scale of biomethane production at a single enterprise exceeds the capacity of gas networks at its location (on a permanent basis or seasonally). For example, gas consumption in the networks in the summer decreases significantly compared to the winter. At the same time, the consumption of motor fuels by agricultural machinery, on the contrary, increases sharply. Given the

[63] National Energy and Utilities Regulatory Commission - http://www.nerc.gov.ua/?id=26436

economic feasibility of the simultaneous operation of two schemes for the supply of biomethane to the end consumer, such the value chain would be viable.

Depending on the type of gas network, gas compressor stations of different pressures will be required to supply biomethane and additional biomethane odorization plant may be required (this may be relevant at connection points with a projected significant proportion of biomethane mixed with odorized natural gas).

The organization of biomethane production depends mainly on the sources of raw materials for biogas production. Because the sources of raw materials can have different potentials and distributed in space, there are several basic combinations in creating a value chain.

The first option involves the production of biomethane at a single enterprise, where a sufficient amount of raw materials for biogas production is produced and its supply will be only local (Fig. 1.13).

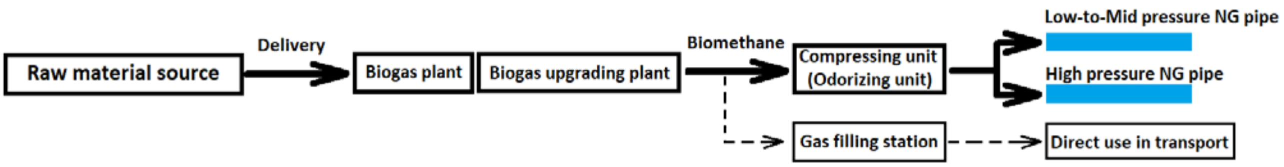


Fig. 1.13 - Biomethane value chain #1

Such schemes are possible only for fairly large enterprises, such as sugar factories, oil extraction plants, poultry farms. At the same time, from a technological point of view, waste or by-products from a single enterprise must be acceptable for stable biogas production. With this aspect in mind, the most likely projects to operate under this scheme are sugar mills, whose pulp mono-fermentation technology is commercial. There are also opportunities for mono-fermentation of poultry litter using commercial litter preparation technologies for stable fermentation, but such an approach will require economic justification.

The second type of biomethane production scheme is more flexible and involves the supply of raw materials for biogas production from various sources (Fig. 1.14).

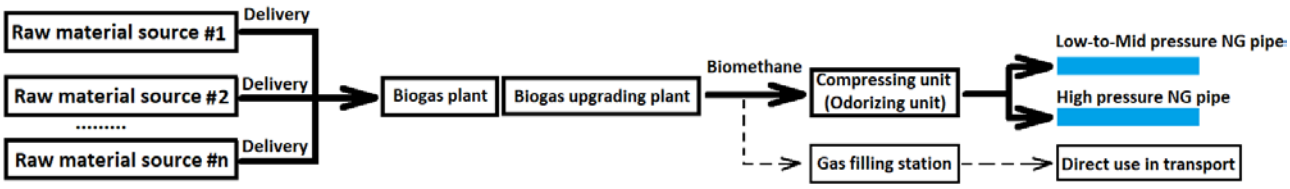


Fig. 1.14 - Biomethane value chain #2

In this case, the base location for the construction of a biogas plant can be selected the most appropriate object, both in terms of logistics of raw materials, and in terms of further logistics of biomethane. For example, the basic object may be a pig farm, where a liquid type of manure is present, and the transportation of which over long distances will be economically not feasible. From other enterprises where by-products with a specific high energy density formed, such products will be delivered on a regular basis (depending on the mode of their formation at these enterprises). The choice of such enterprises will be determined by the economically feasible radius of transportation of different types of raw materials for biogas production. In such a scheme significant volumes of plant types of raw materials can also be supplied, such as maize silage or crop residues. The radius of collection of such raw materials will also be determined by the economic feasibility of their transportation to the biogas plant.

Maize silage is usually harvested once a year and stored at a biogas plant. Its supply for the biogas process will then be local. As for crop residues, their logistics to the biogas plant may be variable depending on the form in which they will be used in the fermentation process.

Example of crop residue supply №1. Cereal straw can be stored in baled form at a location near the biogas plant. From there, the straw can be supplied locally to the biogas plant, where in some special facilities (various mills, extruders, cavitation units, etc.) it will be pre-prepared for the fermentation process.

Example of crop residue supply №2. Cereal straw or other crop residues will be supplied centrally to a separate plant for the production of pellets or briquettes. The location of such a plant will be chosen in terms of the optimal cost of supply of pellets/briquettes to the biogas plant. The supply of pellets/briquettes can be organized both from the pellet plant and to the pellet warehouse at the biogas plant.

Example of crop residue supply №3. Crop residues in granular or briquetted forms from various operating pellet plants will be supplied to the biogas plant. In this case, the supply mode can be selected to minimize the need for storage space for pellets/briquettes at the biogas plant. Given the sufficiently high specific energy density of crop residues in granular form, the economically feasible delivery radius can be quite big, which will cover a significant number of existing industries to ensure the required volume of pellets.

Another alternative consolidation of biomethane projects is the possibility to supply biogas produced at separately located biogas plants via biogas pipelines to the centralized biogas upgrading unit (Fig. 1.15).

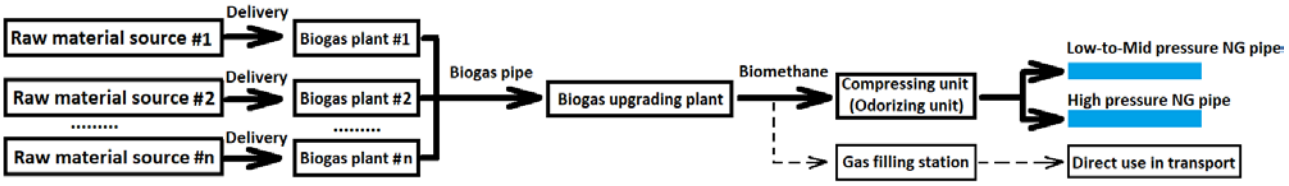


Fig. 1.15 - Biomethane value chain #3

The main limitation of this scheme may be the location of individual biogas plants and related issues of the cost of construction of biogas pipelines, legal aspects of land servitude for the construction of biogas pipelines in different areas, technical possibilities of laying such a pipeline taking into account the terrain, natural obstacles, etc.

<u>Synthetic methane from green hydrogen</u>

The value chain #1 includes utilization of RES electricity for green hydrogen. methanation for biomethane production and pumping of biomethane to gas grid then consumed by consumers connected to gas grid as described in previous chapters (Fig. 1.16).

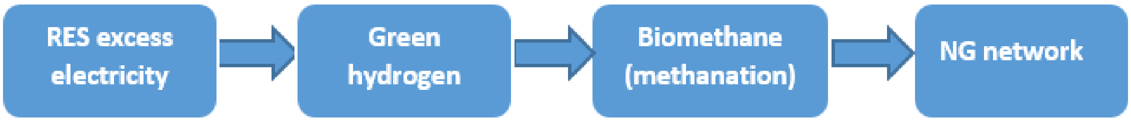


Fig. 1.16 - Value chain #1

The principal realization of value chain shall include special configuration of capacities distribution and location. It is necessary to combine within one site (or within adjacent sites in form of "technical park") the biogas production facility, infrastructure for biogas-to-biomethane upgrading, methanation complex and hydrogen production facility (and auxiliary infrastructure) to avoid intermediate transportation/storage of products on each stage. The "excess RES electricity" could be acquired from the grid connection for the whole complex, however it is desirable to combine within the installation

Another value chain can foresee the production of green hydrogen from biogas/biomethane and water (reverse methanation process) and then utilization of generated green hydrogen on site or close to the site at industrial application or direct consumption as motor fuel on transport.

As transport consumes ca. 25% of all energy (GFEC) in Ukraine, this value chain may be as important as NG grid-pumping (Value chain #1). Such facilities are generally linked to the concentration of gas filling stations (which. in their turn. are linked to the population centers and industrial areas). However, methanation complex may be located in any place far from concentration of transport consuming, and biomethane may be transported by trucks to the point of consumption (as it is done with conventional fossil-fuel gas filling, as gas production facilities are not adjacent to gas filling stations concentration).

Also. this value chain may be combined with value chain #1 to compensate seasonal fluctuations of consumption of both consumers – summer lower consumption of gas network and higher consumption of transport and vice versa. The main factor determining location of the production facilities of biomethane is feedstock availability. For this scheme also the option of integration of RES generation facilities on site may be considered, as there is no criteria of NG grid connection.

Ukrainian main and distribution gas pipelines structure taking into account the geographical distribution of BM production potential

Due to highly developed existing natural gas supply network in Ukraine (both gas transit system (GTS) and gas distribution system (GDS) with all necessary infrastructure potentially compatible for biomethane transmission as technically close analogue of natural gas (storage facilities, pipelines, valves, regimes of operation, operator instructions, automatics, personnel qualification), the biomethane acquisition and transportation into gas grid may become one of the priorities for Ukrainian GTS and GDS. Distant rural areas where biomass feedstock for biomethane production is generated (and where the biogas plants, gravitating to the feedstock are likely to be implemented) are mostly covered by GDS connected with main pipelines which (prior to project implementation) may simplify technical issues for connection to the grid and reduce potential project costs.

In 2020 Gazprom reduced the transit through Ukraine on 38% to 55.8 billion m3 of natural gas per year. This is the lowest indicator for the latest 30 years. Having the designed installed capacity of 146 billion m3 for only transit (not including capacities for internal consumption), the average load capacity factor for trunk pipelined in terms of transit pipelines drops to 0.37 and in terms of total pipelines (transit and internal consumption) less than 30%.

The connection of existing main gas pipelines of Ukraine to the European hubs for possible biomethane export and reduction of potential risk of underload of Ukrainian gas transmission network due to possible NG transit drop down make NG substitution by biomethane highly desirable.

<u>Criteria for selection of priority zones for biomethane plants connection to gas networks.</u>

Before starting the analysis, it is necessary to define the criteria according to which the selection of points/zones of BM plant to gas networks will be done. The principal criteria are formulated as follows:

1) Zones with the **highest concentration of feedstock for biomethane potential** (in complex, including all types: manure, wastewater, MSW, residues, silage, “green” hydrogen);
2) “Local bushes” of consumption on **gas distribution networks (GRP/SHRP/GRS)** with **annual consumption** at least **5-10** million nm3/year and consumption of **minimal month** at least **200-400** ths. nm3/month;
3) **Industrial facilities** with individual large and stable annual gas consumption linked to GRS/SHRP/GRP which could be potentially covered by **CBAM** (steel/aluminium, cement, chemical industries);
4) **Encircled zones of gas transmission pipelines** and “**root-based**” points of branches “transmission pipeline”→GRS;
5) Zones of **15 km** from transmission main pipelines;

6) Zones of gas distribution networks **redesign** which increase the consumption of local bushes[1] including plans for natural gas plants construction, increasing of gas debit to gas pipeline, own plans of gas companies for biomethane/biogas pilot projects implementation and existing operational biogas plants which potentially will inject biomethane to the grid;
7) Zones/points with **available infrastructure** on main transmission pipelines (compressor stations, gas distribution stations, underground storages), "debit gas installations[2]" (gas extraction / production / preparation);
8) Zones of high concentration of **gas filling stations**;
9) Zones of potential decentralization/disconnection from transmission gas grid due to transit drop and general redesign of gas system.

Macro analysis for potential biomethane connection points on the level of TSO

The TSO operates in total 33 thousand km of trunk transmission pipelines, 57 compressor stations, 524 gas compressors (4.5 GWel of installed capacity), 1389 gas distribution stations (GRS). The total installed flow capacity of the GTS is 435 billion nm3/year cumulative on entrance point and 146 billion nm3/year cumulative on exit point. Transmission pipeline operation regimes is typically connected with fluctuations of consumption during year – with minimum consumption in summer period and maximum in winter period with the average weighted ratio of max/min as 5/1 (for last 5 years). This ratio, despite drops of absolute values of consumption/production is remaining more or less stable from year to year (see Fig. 2.1).

The internal consumption dropped from 54 million nm3 (in 2012) to 29 million nm3 (in 2019). For 2019, total natural gas extracted from trunk pipeline for internal consumption for local distribution gas companies averaged in 24.3 billion nm3/year (absolute historical minimum since 1991). Overall transit of gas averaged in 55.8 billion nm3/year (2020). Technical consumption of natural gas for own needs of gas distribution system averaged in 7.6 billion nm3/year (2020). Thus, the overall natural gas flow in GTS is averaged in 80 billion nm3/year (2019-2020 season) out of 289 billion nm3/year (entrance - exit). For the mentioned flows capacities has average capacity load factor averaged for latest 5 years as 0.28.

[1] This term include any kind of installations which insert natural gas to the grid: gas production, preparation, cleaning, gas drills, gas extraction, underground gas storages (PSG) other gas enterprises which could insert gas to the grid.
[2] "Debit gas installation" means any type of installation which takes gas from grid and/or inject gas to grid. The respective areas/sites include separate technological points/segments of gas grids (including compressor stations and gas distribution stations) with the connected "debit gas installations" and where the grid has the excess capacity for gas acquisition. Biomethane plants may be also integrated into "debit gas installations" (for example, gas preparation installations are complex enterprises in terms of infrastructure with different installations, processes and spectrum of feedstock and products. In this context, the classical oil refineries and/or oil chemical plants/fertilizer plants linked to distribution network and other gas/oil refining objects/terminals connected to the gas grid may be also considered as priority sites for biomethane plant in terms of available infrastructure which could potentially reduce infrastructure costs

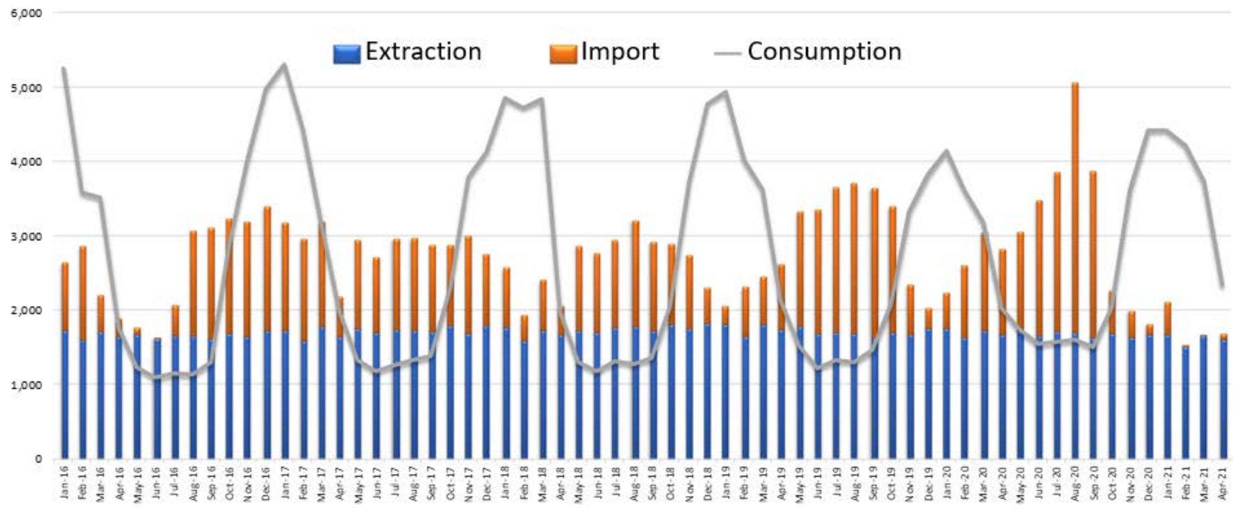


Fig 2.1 − Gas balance in Ukraine, including seasonal fluctuations (million nm3/month)

Natural gas may be supplied directly from the GTS to the individual gas consumers (large industries, CHPs and supporting infrastructure) or from TSO to the gas distribution regional companies and then via branched gas distribution systems (through GRS and final end-line object GRP/SHRP) to the end consumers. GRP/SHRP typically supply gas to the small bushes of consumers (like households, small district heating companies, budget facilities), however may also supply gas to large enterprises and CHPs/large district heating companies with high natural gas demand depending on local distribution schemes.

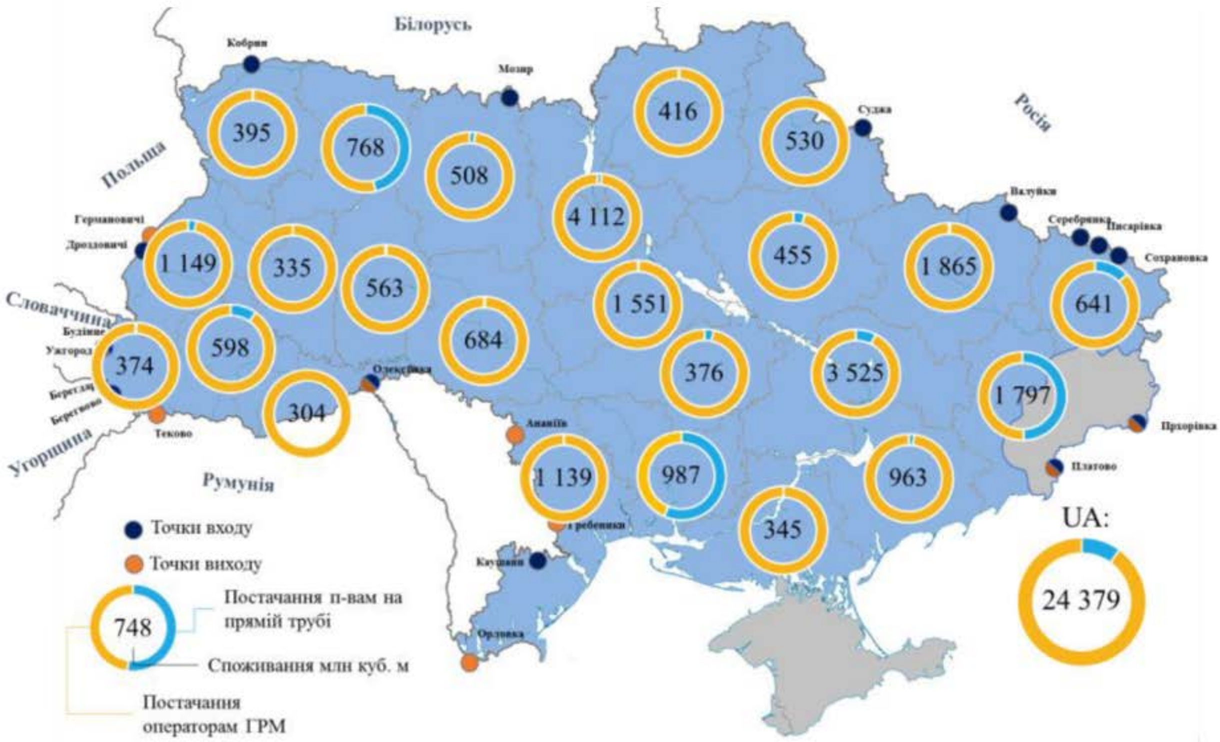


Fig 2.2 − Quantities of natural gas extracted from trunk networks of TSO to gas distribution networks of regional gas supply companies per each region of Ukraine (million m3)

The overall capacity load factor for entrance and exit points of Ukrainian GTS for the latest 3 years (2016-2018) is in range 0.25-0.33 which is the lowest indicator for the last 30 years.

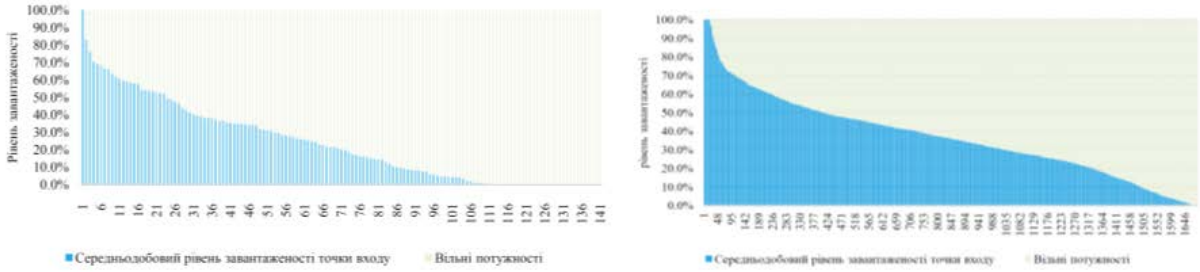


Fig 2.3 − Capacity load for entrance (left) and exit (right) points for Ukrainian GTS.

The overall capacity load factor for GRS in Ukraine is, analogically to trunk pipelines, extremely low. Only 4% of GRS has load factor between 50% and 100%, and half of GRS has load factor less than 10% (usually 3-5%), with the average of 0.1…0.12. This underload, in its turn, influence on the next part of distribution system of regional gas distribution companies (Oblgases), which depends on the region and local conditions and consumers on each GRP/SHRP. Not all points of local distribution networks are uniformly underloaded. Some of the points have capacity load factor of 0.8-0.9 (for large enterprises, CHPs, few GPRs which has been recently reconstructed/united for one GRP) and they may be considered as potential “candidate” points for biomethane plant connection (see below para A 2.2-A 2.3). Underloaded points are usually considered as not suitable for biomethane plant connection (except of cases with large absolute consumption), as nobody will consume additional biomethane injected to the grid if there is current lack of exiting consumers.

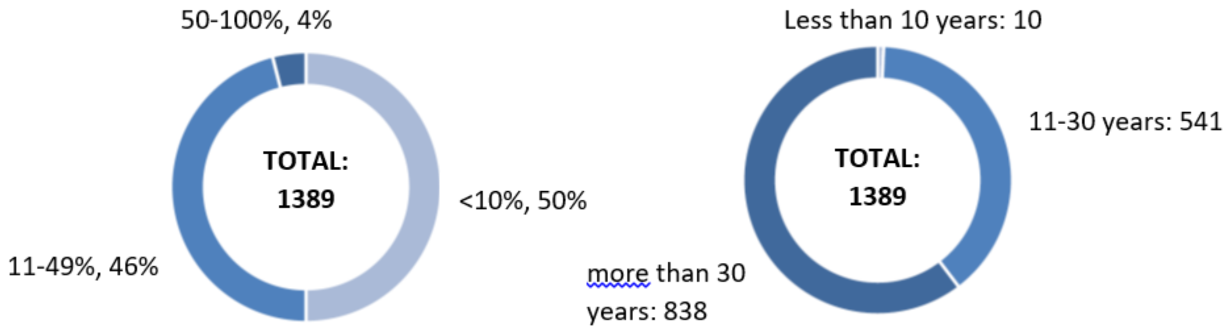
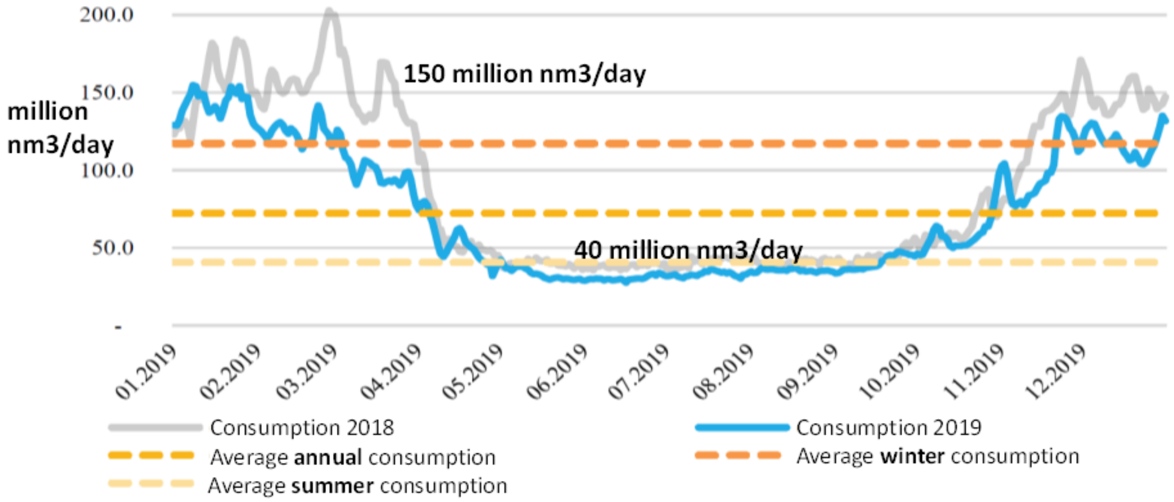


Fig 2.4 − Capacity load factor for regional gas substations (GRS) (left)
and term of operation (right)

The non-uniformity of consumption and distribution is also connected with seasonality in Ukraine. In winter, mainly due to the higher heating demand (and also due to other factors, for example, higher demand on own needs of GTS), natural gas consumption is higher and in summer – lower.



40 million nm3/day * 365 = 14.6 billion nm3/year

80% from 14.6 billion = 11.6 billion nm3/year

Fig 2.5 − Seasonal distribution of gas consumption for 2019, million nm3/day[3]

The important conclusion from the figure above is that daily peaking in winter/summer season correlates as 150 million/day to 40 million/day (factor of 3.75). This means, that the baseload summer consumption for whole Ukraine is rather high, and if recalculated for annum, it will equal to 14.6 billion/year (50% from total annual consumption). The biomethane potential is assessed (depending on the year) as 8.5-9.5 billion m3/year which is 2 billion lower then 80% from the "baseload annual consumption". That is why network consumption could not be considered as limitation factor for biomethane potential with respect to injection to the grid or, in other words, theoretically all biomethane may be injected and consumed within the Ukrainian GTS even in baseload regime. However this also means that without biomethane injection to transmission networks with high pressure it is impossible to use all potential for grid pumping.

As for the trunk pipelines system and infrastructure, there are the following routes of gas transmission pipelines in Ukraine:

- Soyuz;
- Urengoy-Pomary-Uzhgorod;
- Progress;
- Shebelynka-Poltava-Kyiv (SHPK);
- Shebelynka-Dynanka-Kyiv (SHDK)
- Elets-Dynanka-Kyiv (EDK);

[3] Sources: Plan of Development of GTS developed by Transmission System Operator LLC for 2021-2030
План розвитку газотранспортної системи ТОВ «Оператор ГТС України» на 2021–2030 рр. https://tsoua.com/gts-infrastruktura/rozvytok-gts/10-richnyi-plan-rozvytku/
Balance of Ukrainian gas market: https://docs.google.com/presentation/d/1q0UKFYH4OQBXXDq-sl27xlslGy9Qsndb/edit#slide=id.p1

- Elets-Kursk-Kyiv (EKK);
- Kyiv-West UA I and II;
- Dashava-Kyiv;
- Elets-Kremenchuk-Kryvyi Rih (EKKR);
- Shebelynka-Dnipro-Odesa (SHDO I and II)
- Shebelynka-Dnipro- Kryvyi Rih-Izmail (SHDKRI);
- Ananiv-Tyraspol-Ismail (ATI);
- Kremenchuk-Ananiv-Chernivtsi-Bohorodchany (KACHB);
- Dolyna-Uzhgorod-Derzhkordon I and II (DUD I and II).

Firs three ones are the main transit transmission gas pipelines, others are mainly serving for internal supply in Ukraine and to serve for the debit gas installations to let them insert their extracted gas to the GTS (and transport from the extraction places to the consumption places). Transit gas transmission pipelines have the diameter of 1000-1400 mm and have the individual capacity of 4.5-30 billion nm3/year of natural gas for each segment with the working pressure from 45 to 75 bars (60-65 bars in average).

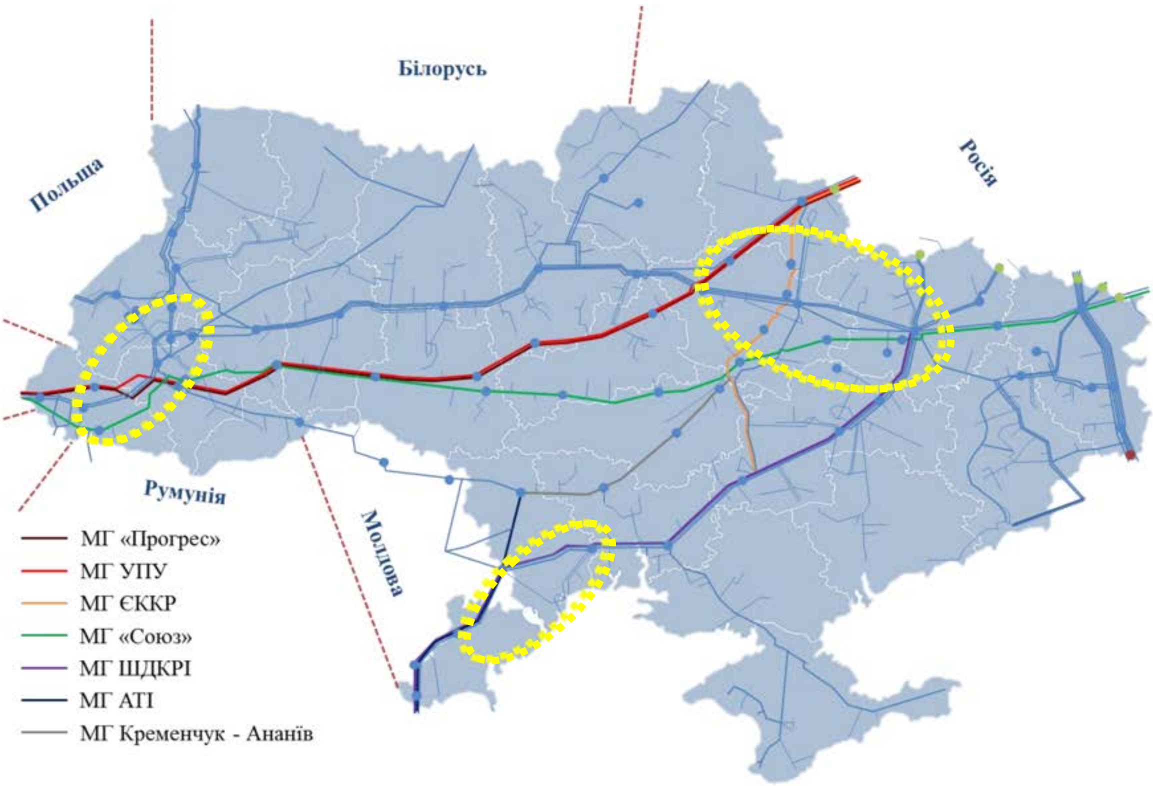


Fig 2.6 − Map of GTS and compressor stations with preliminary indication of most priority areas in terms of capacity, zones of connections and available infrastructure

Compressor stations with auxiliary infrastructure and points of interconnections and cross connections of transmission pipelines are the object of particular interest with respect to potential connection points for biomethane plants. The main concentration of this infrastructure is observed in three main zones in Ukraine – Western (Lviv, Ivano-Frnakivsk, Zakarpattya regions, where all three main trunk pipelines are getting together), Eastern (Kharkiv and Poltava regions, where there is developed infrastructure and pipelines serving for gas extraction and preparation/production/refining with the segments of two main trunk pipelines are located) and southern (south of Odesa and Mykolaiv region).

The distribution part of transmission networks operated by TSO is represented, as mentioned before, with 1389 gas distribution substations (GRS) with cumulative capacity of 1.3 billion nm3/day (or 475 billion nm3/year on nominal, equivalent to maximum gross capacity of transmission network) with average capacity per single GRS of 0.94 million nm3/day (or 345 million nm3/year). The main function of GRS is reduction of pressure and odorization of natural gas coming from trunk pipelines to the distribution system/facilities of regional gas distribution companies and, finally, to end customer. The typical GRS reduce pressure from 40-75 bar in trunk pipeline branch to 3-12 bar in distribution networks. The pressure range of 6-12 bar (high pressure distribution networks) is only used in distribution systems with large consumers (industries, CHPPs, large boiler houses), ca. 10%-15% of GRS reduce pressure to 6-12 bar, 85% – to 3-6 bar (average pressure distribution networks).

The available capacity of GRS is 7-8 times higher than any peak natural gas consumption in Ukraine (for example, one day in 2019-2020 the peak gas consumption was 169 million nm3/day (7.7 times less than cumulative GRS capacity) and 15-20 times higher than daily consumption on average annual basis (70 million nm3/day in 2019-2020). This mean that the average capacity load factor of GRS, as already mentioned, is extremely low, 0.1…0.12 in average.

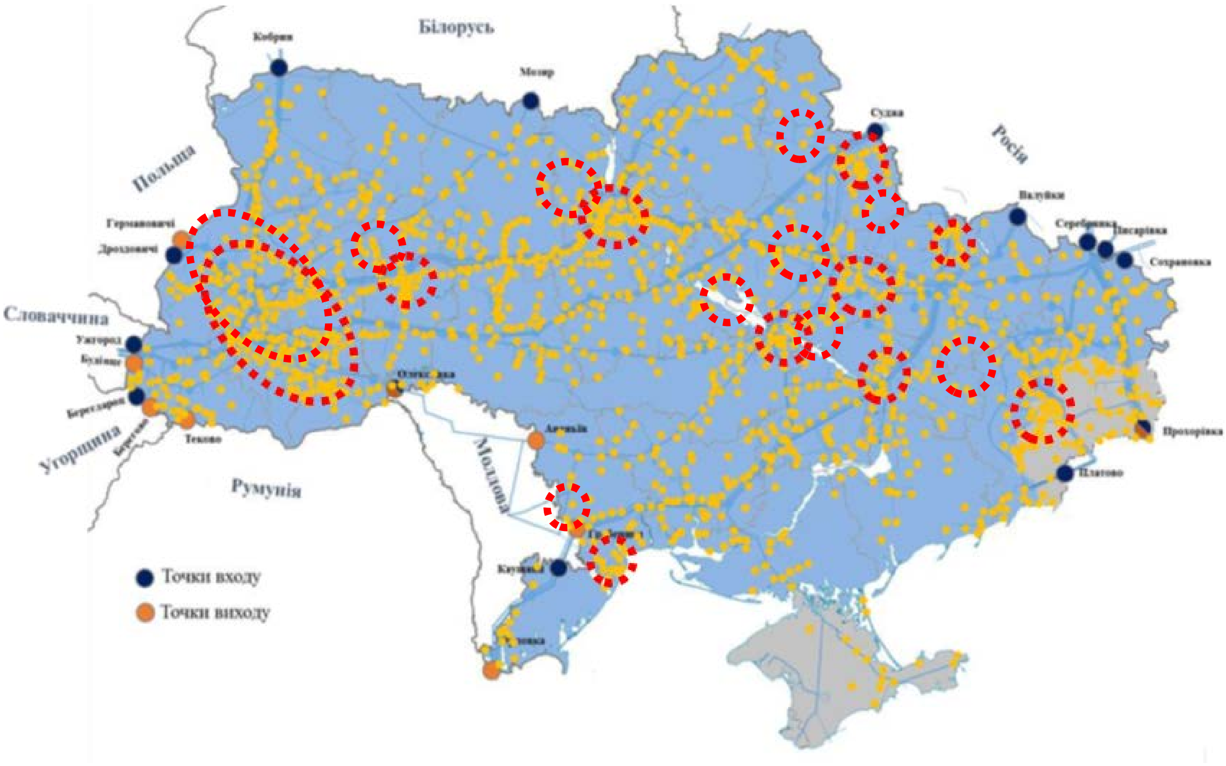


Fig 2.7 − Mapping individual regional gas distribution substations in Ukraine and priority areas in terms of available points for connections

The GRS is also the first point (after extraction from trunk pipelines) where the measurements of pressure, temperature and quality parameters of natural gas is performed and also the odorization process of gas is performed. Most of the GRS is old-style module buildings (individual design or typical design, for example BK-GRD-80, BK-II, BK-III) with semi-automatical regime of operation commissioned in 1970-1980s. TSO is gradually preforming the reconstruction of GRS with respect to decommissioning of most outdate and underloaded ones and circling of their branches with another ones increasing the capacity load factor. Also, GRS which will continue operation will be gradually reconstructed from semi-automatic regime to fully automatic with application of SCADA remote control.

The geographical mapping of GRS show, that their distribution in Ukraine is more or less uniform and is mainly gravitating to the population centers, industrial areas and gas extraction sites. The most concentrated areas with most available GRS (as per quantity and also load) are highlighted with red line on Fig 2.7 – L’viv and Ivano-Frankivsk regions, area around Kyiv city local bushes around Khmelnytskyy city, Kremenchuk, Dnipro, Shebelynka oil ans gas extraction, Kharkiv, Eastern Ukraine (Donetsk-Kramatorsk industrial agglomeration, Khartsyzk industrial agglomeration), Odesa and Mykolaiv (gas terminal, port Yuzhne, Odesa port plant, agroterminals, oil extraction, Mykolaiv aluminum). This zones are the potential candidates for connection of large scale biomethane plants.

Priority areas for biomethane connection may be the sites where gas peaking will be installed to balance the power system if Ukraine. Ukrenergo has already developed the map of priority areas/zones for such objects. From the other hand, there is a map of location of compressor stations (in operation and planned for decommissioning) published by TSO. Superposition of these two maps give the information of the priority sites for biomethane connection (see Fig. 2.8).

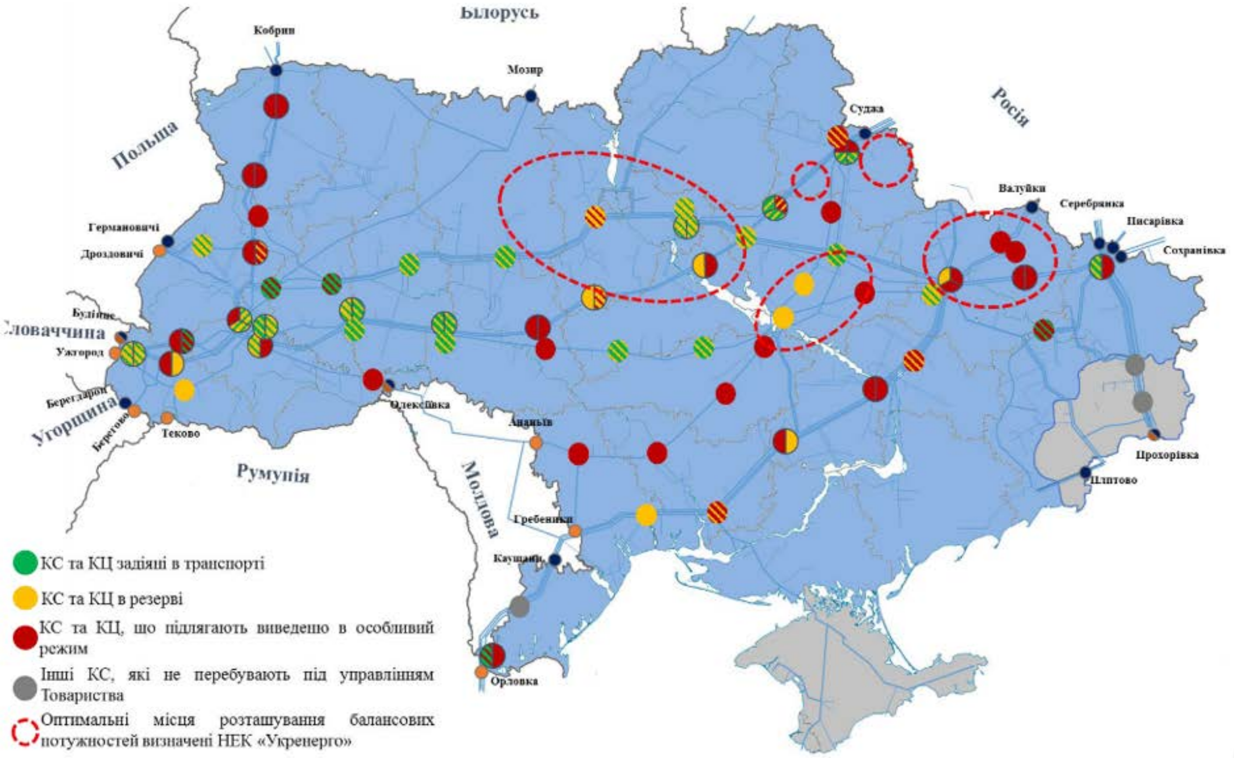


Fig 2.8 − The map of compressor stations and priority areas (red line) of balancing capacities construction according to Ukrenergo (2000 MWel of gas peaking)

The concrete sites locations of compressor stations are presented in Annex 2-1.

As the projected biomethane plants may use renewable hydrogen as feedstock for biomethane production (through methanation process), the map of most perspective hydrogen production zones may additionally highlight the priority zones for biomethane plants location. Such map is already publicly available (see Fig. 2.9).

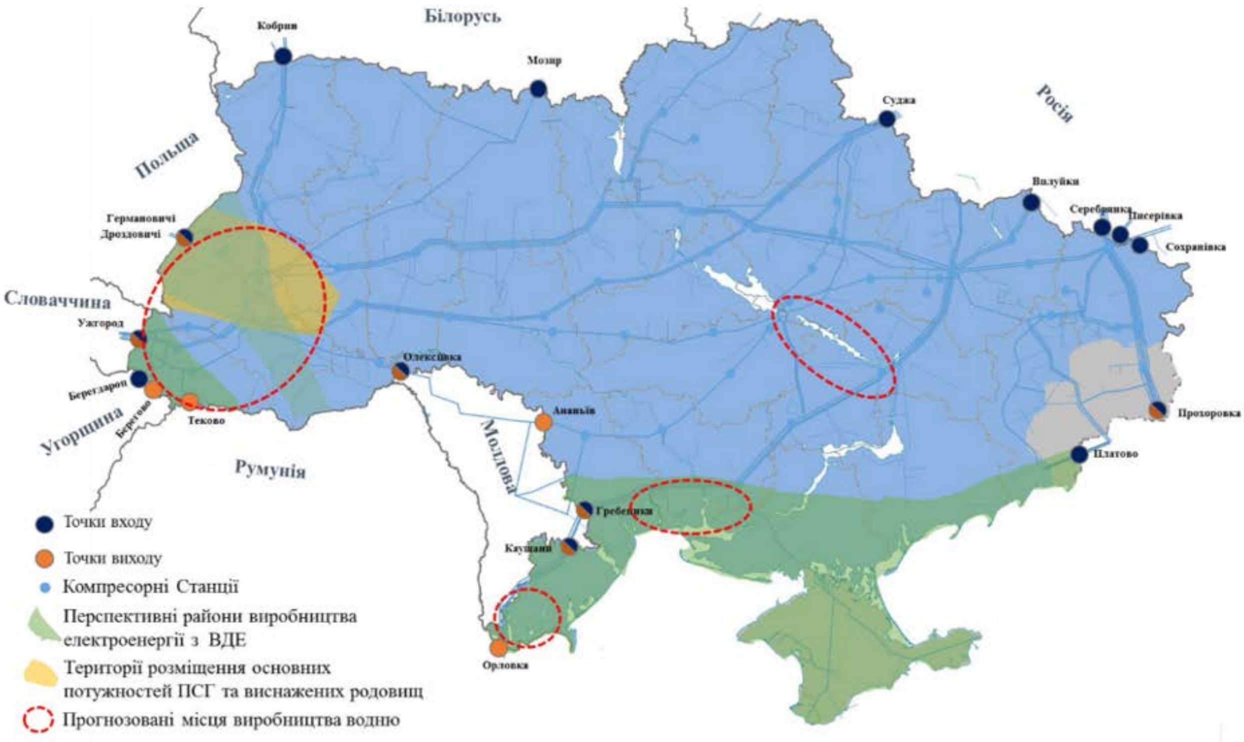


Fig 2.9 – Perspective zones for renewable hydrogen production (red line)

In case of complex production of hydrogen and biomethane within one site, the transmission trunk pipelines may also transport mix of biomethane and hydrogen which increase the flexibility of biomethane facility located in the highlighted zones. In case of hydrogen and biomethane production on separate facilities, the biomethane plant may be located as close as possible to the independent hydrogen producer. According to the map, the most priority areas are Lviv, Zakarpattya, Ivano-Frankivsk, south of Odesa region, south of Mykolaiv region.

Underground gas storages (PSG)

PSG in Ukraine are operating under Ukrtransgas (separate company unbundled from TSO) according to typical annual schedule pumping (Fig 2.10) – pumping (inserting) gas during summer season and releasing gas during winter season. Such fluctuation graph is also very typical for the EU-28 gas storages. In this process, however, there is a constant value – minimal gas volume, below which PSG is never operating (due to different reasons, mainly technological) which is characterized by the cumulative capacity of whole PSG system – for Ukraine this value is around 7-8 billion nm3/year.

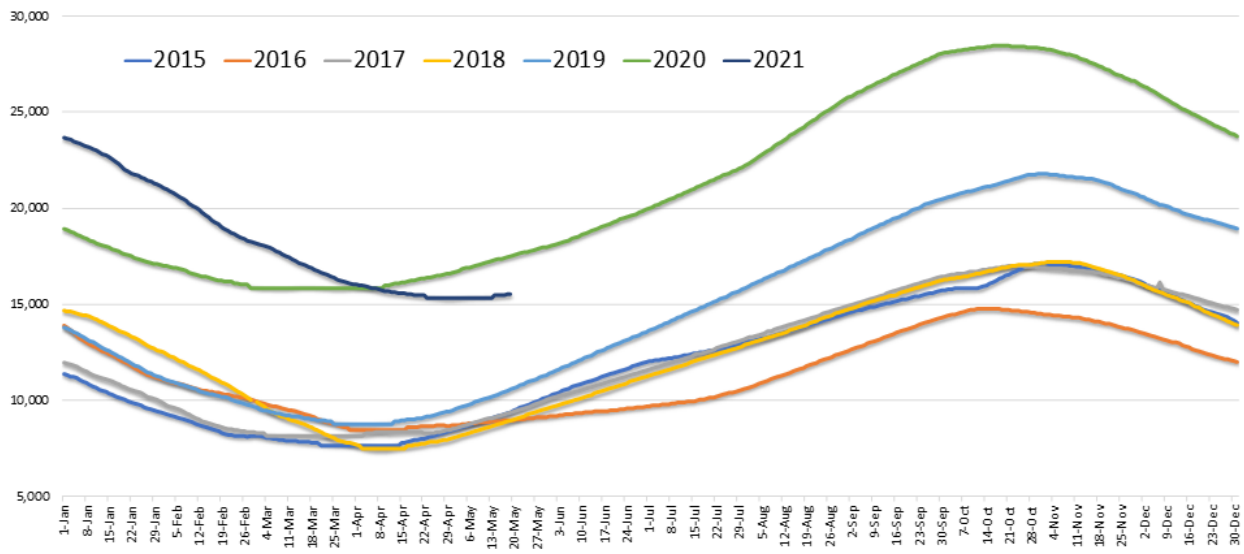


Fig 2.10 − Seasonal fluctuation of natural gas stockpiles in gas storages during 2015-2021

Total volume (maximum pumped-in capacity) of PSG in Ukraine is 30.8 billion nm3. For the May 2021, the PSG has been filled in on the level of 45% (see Fig 2.11). The structure of gas capacities of PSG used by different companies is diversified, the core volumes are owned by Naftogas (49%), TSO operates only 14%. Also, there is large share of non-residents (international companies) – 33%. As Ukrainian transmission system is connected to the international hubs, they have a possibility to use PSG at any point of the system from gas extraction to gas consumption (including Ukrainian part).

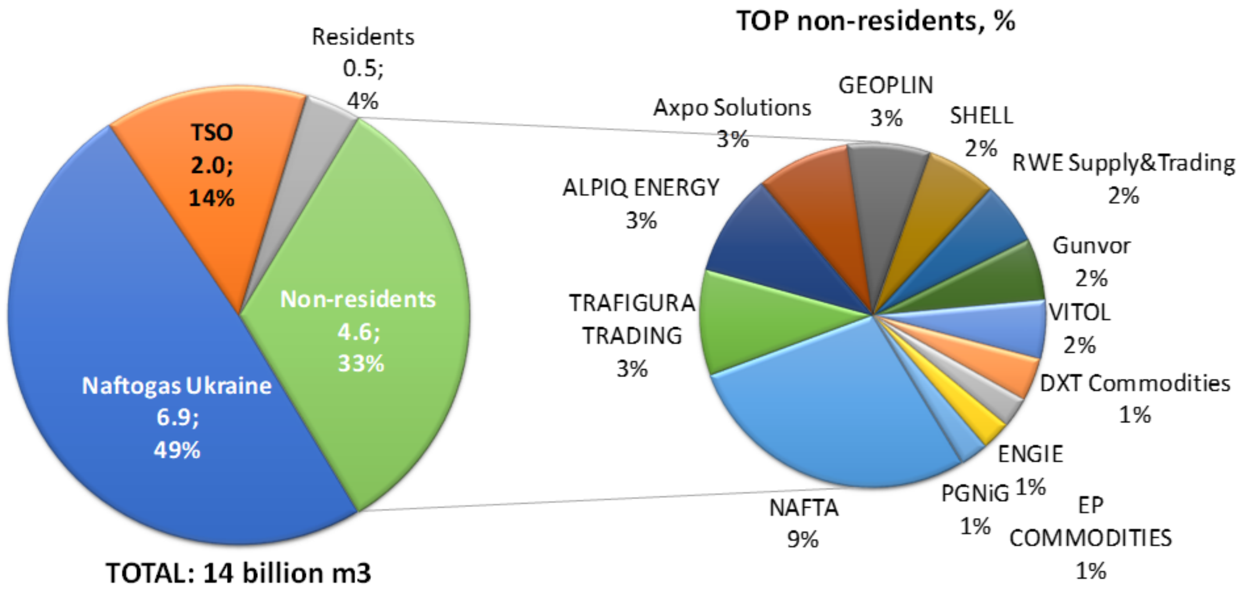


Fig 2.11 − Structure of storage of natural gas in PSG (May 2021)

The PSG in general meaning is the large complex with all infrastructure for gas compressing, decompressing, heating/cooling, separation, purification, technological complex for auxiliary facilities, etc. The typical view of Ukrainian PSG (as example, the largest Ugerske PSG is taken) is presented below on Fig 2.12.

Fig 2.12 − Typical view of the PSG (on the example of Ugerske PSG)

The infrastructure available at PSG may provide additional compression capacities. In this case biomethane complex may consider installation of boosting compressor station for pressing to lower pressure in comparison with direct connection to random point in trunk transmission pipeline. Biomethane plant directly connected to PSG at the entrance technological point may insert biomethane with compressing to some pressure level which is typical for PSG entrance (for example, 40-45 bar, same level as on the GRS branches). Biomethane may be physically pumped directly to PSG (then PSG is serving like huge virtual biomethane consumer linked to one geographical point with clear connection conditions and stable schedule of consumption). That is why all PSG in Ukraine are potential candidates for large-scale biomethane plants connections.

There are 12 main PSG in Ukraine, with different capacities, two of them (Ugerske and Bilche-Volytsko-Ugerske) covers 60% of total capacities. The operative conditions of PSG as for 7 June 2021 is presented below.

Table 2.1 Operation of Ukrainian underground gas storages (PSG) for 7 June 2021, million nm3[4]

Name of PSG	Total pumped in gas	Active gas for long term storage	Technologic gas	Pumped in (last day)	Debit (last day)	Designed capacity
Ugerske (XIV-XV)	460	250	210,93	2,68	0,00	1900
Bilche-Volytsko-Ugerske	9984	3700	6284,27	0,00	0,00	17050
Dashavske	1294	622	672,23	0,00	0,00	2150
Oparske	372		372,54	10,38	0,00	1920
Bohorodchanske	1630		1630,99	0,00	0,00	2300
Olyshivske	95	90	5,95	0,00	0,00	310
Mrynske	755		755,55	3,27	0,00	1500
Solokhivske	522		522,26	0,00	0,00	1300
Proletarske	157		157,34	0,00	0,00	1000
Kehychyvske	253		253,84	0,00	0,00	700
Krasnopopivske	53		53,91	0,00	0,00	420
Vergunske*	175		175,86	0,00	0,00	400

[4] https://utg.ua/utg/business-info/live.html

TOTAL	15757	4662	11095,69	16,32	0,01	30950
Free capacity:					14414	

Geographical distribution of PSG is non-uniform, there are basically two main "bushes" – western (up to 65% from total capacities located in L'viv and Ivano-Frankivsk region, mainly serving for transit balancing and provision of gas storage services to non-residents) and North-Eastern (Sumy, Kharkiv, Poltava, Luhansk regions mainly serving for internal consumption balancing, provision of required gas consumption schedule to large industries and extraction balancing).

Fig 2.13 − Mapping of PSG location

The PSG entrance points and main infrastructure locations is clearly identified on the map (see geographical locations of all PSG in Annex 2-2):

Debit gas installations – extraction, preparation, production, purification.

Total gas extraction in Ukraine for the latest 5 years has been stable on the level of 20.1-21.5 billion nm3/year (gross), in 2019 – 20.7 billion nm3/year (69% from internal consumption). The gross extraction include also consumption for own needs of gas extraction infrastructure, which is increasing due to exhausting of gas drilling points (around 20-25% from total extraction).

The extracted gas is pumped into GTS through the special connection points (usually on GRS branches or directly connected to GRS) geographically linked to the same zones/fields where it is extracted. The points of gas inserting into GTS with the largest capacity are located in Poltava and Kharkiv region (Shebelynka gas extraction field), L'viv and Ivano-Frankivsk regions (Dashava, Boryslav, Drohobych gas extraction fields) and partly in Luhansk and Donetsk regions (Yuzivske gas and oil extraction field) – see Fig. 2.14.

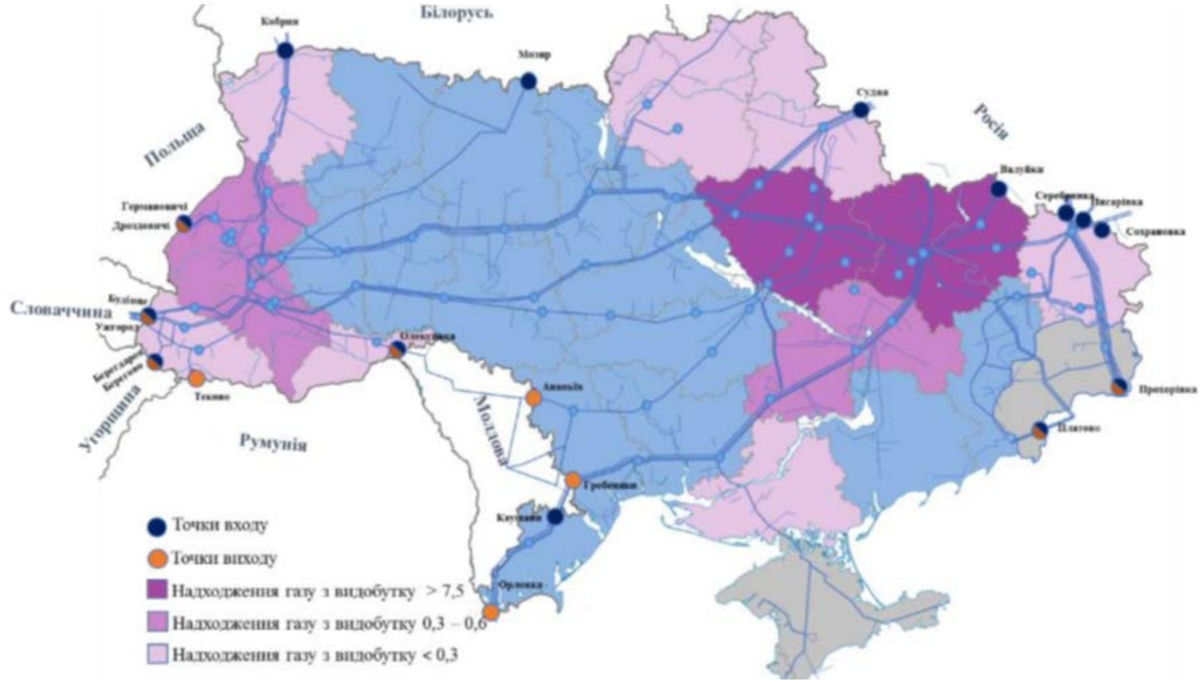


Fig 2.14 − Macro distribution of “debit gas installations” (as per quantity of extracted gas inserted to GTS) (billion m3/year) in 2019.

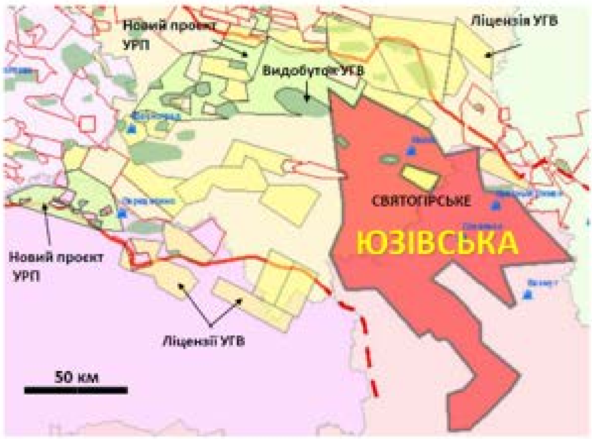
Most of amounts of the natural gas is extracted Kharkiv and Poltava regions – ca. 18 out of 20.5 billion nm3/year. The points of extracted gas inserting are the potential connection points for biomethane plants as from the GTS point of view biomethane plant and gas drill are virtually the same “gas debit installation” supplying gas to the network. The points of connection also include all needed infrastructure (compressing, gas intermediary storage, gas purification, drying, preparation, separation, collection, etc.) and are in most cases underloaded due to exhausting of drills and reserved designed peaked capacity. This creates free capacity for connection of additional gas flow from biomethane plants.

In Western oil and gas extraction zone, there are several operators. The available data for one of the operator (ZakhidNadraService Ltd.[5]) shows that existing gas drills/separation points are suitable for biomethane plant connection with up to 36 million nm3/year capacity (uniform during year).

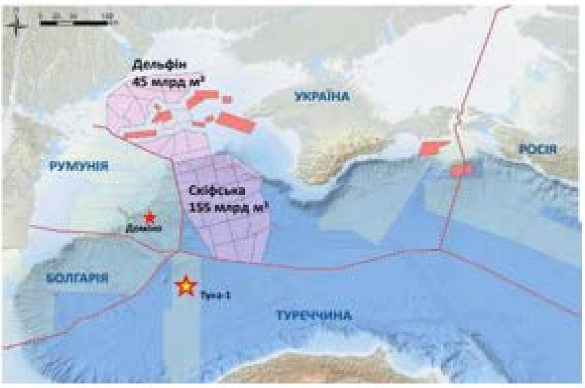
The picture of gas extraction is not static, the NPC Naftogas Ukraine and UkrGazVydobuvannya has the approved plans for development of gas extraction infrastructure and increasing the internal extraction capacity till 2030. The mapping of perspective gas extraction fields is presented below (Fig. 2.15).

[5] http://www.zns.com.ua/

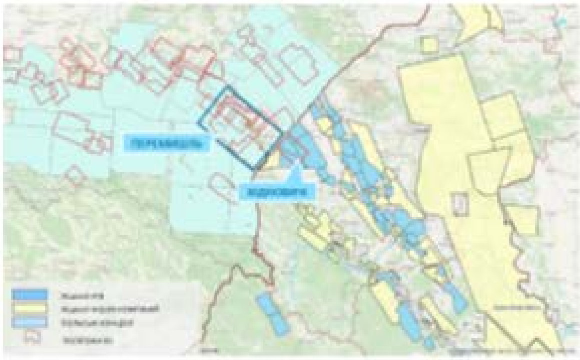
Perspective gas extraction fields in Ukraine



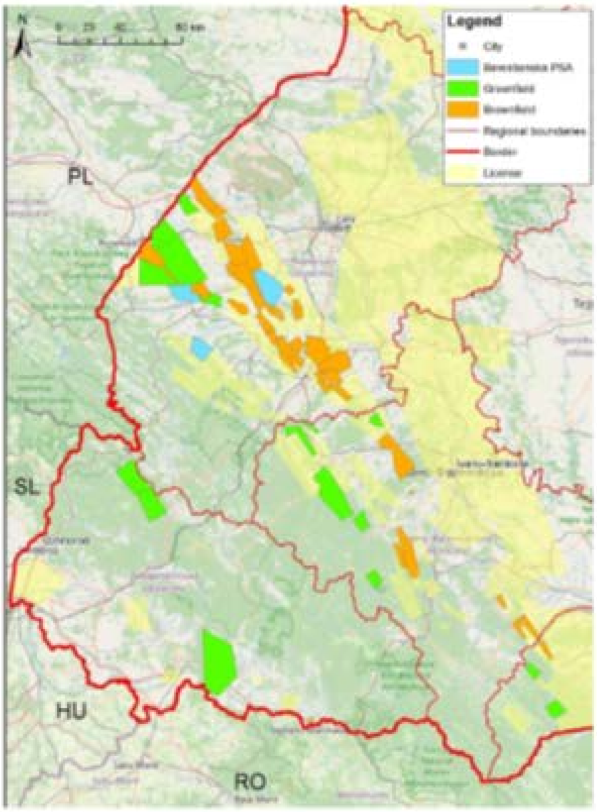
Yuzivska extraction field



Black sea extraction fields



Hydnovychy perspective oil and gas extraction



Carpathian extraction fields

Fig 2.15 – Perspective gas extraction zones in Ukraine

Zones with the highest planned capacities are located in Eastern Ukraine (Yuzivkse gas and oil extraction field), Western Ukraine (local fields in Lviv, Ivano-Frankivsk, Zakarpattya regions) and black sea shelf.

Yuzivska perspective extraction has the capacity of 1,200 billion m3 total identified stocks, plan to have 17 billion nm3/year extraction capacity in 2030 (15 drills) in cooperation with project "Tight Gas".

Carpathians perspective extraction has the total capacity of 2P stocks identified for up to 30 billion nm3 (De Golyer & McNaughton 1 Jan 2020) – the most perspective sites to be commissioned till 2030 are Tatalivska, Petrovetska, Berestyany sites.

Black sea perspective extraction (planned connection to southern trunk pipeline “АТІ”, “ЕККR” and “Shebelynka-Ismail” (Odessa and Mykolaiv region, port Yuzhne, Oleksandrivske industrial park) has the total capacity of 200 billion identified stocks, plan to have 10-16 billion m3/year extraction in 2030-2040, first industrial gas in 2025-2026. The region already has similar implemented projects: Tuna – analogical project in Turkey, Domino – analogical project in Romania sea shelfs.

Hydnovychy perspective extraction has the total capacity of 8 billion nm3 identified in neighbour Peremyshl oil and gas extraction site, Polish company PGNiG identified 2 billion m3 stocks in Hnydovychy (total forecasted 20-60 billion nm3), start of extraction in 2024 (50-100 million m3/year).

All mentioned zones has to be considered as priority for biomethane plant connection with respect to available consumption and infrastructure.

Own plans of TSO for biomethane/biohydrogen projects developments

The TSO has its own views on the biomethane integration to the transmission network in Ukraine (see Fig. 2.16).

The essence of the concept proposed by TSO is dictated, among others, by the current underload of GTS and the potential risk of full stop of transit after 2024 (end of transit contract with Russia). In this case the GTS will have much lower load, but at the same time will consume at least 5 billion nm3/year for support of its functionality. So, the inserting of additional natural gas (and biomethane/hydrogen) is highly desirable for TSO to increase the load factor of GTS.

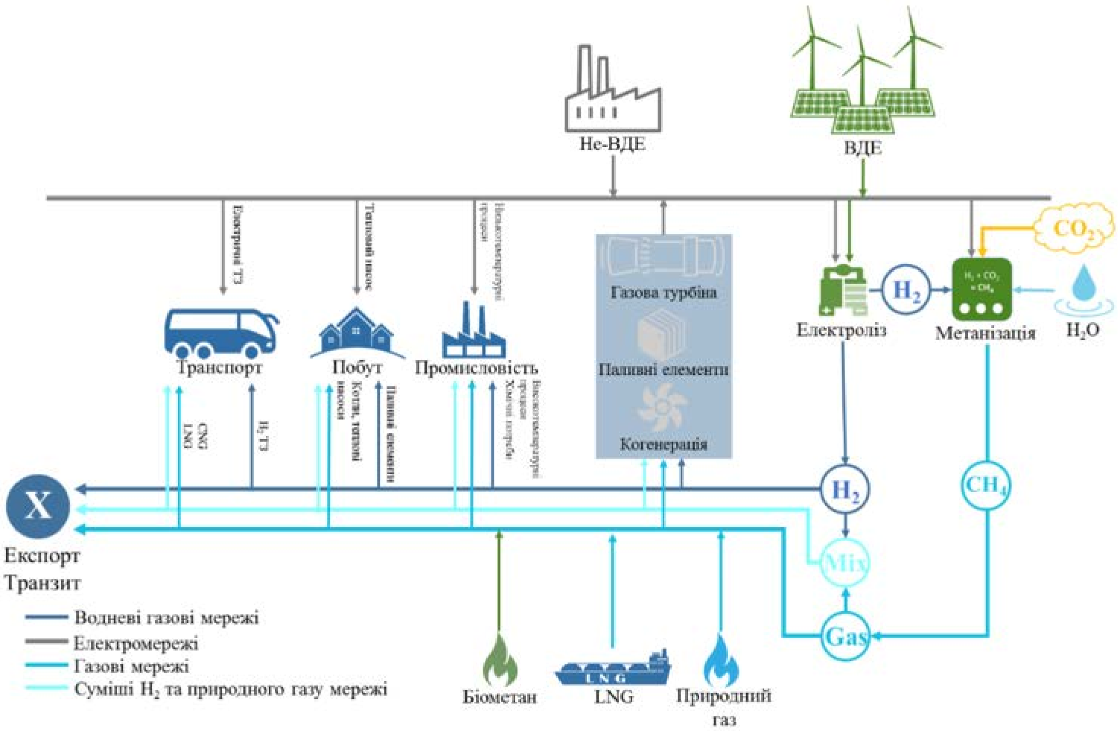


Fig 2.16 − General concept of renewable gases integration to GTS by TSO

The TSO is already performing the investigations for hydrogen transportation (and its mix with natural gas) in GTS, pilot project for biomethane production, considers different options and concepts for biomethane plants potential connection to GTS.

For biomethane, the concept of its integration according to TSO views, shall foresee (Fig. 2.17):

1) Direct connection to the trunk pipelines of transmission line (with compressing to 45-75 bar via boosting compressor station (Ukrainian: «дожимна компресорна станція (ДКС)»));
2) Connection to the gas distribution pipelines (with compressing to 0.5-3 bar pressure (GRP-consumer bushes), and to 3-12 bar (GRS-GRP bushes) via boosting compressor station within the separation and purification station of biomethane complex).

In case of biomethane surplus over consumption of regional distribution gas network, the boosting compressor station will insert it till the reduction point of GRS (with upper limit for biomethane accounted as 70% vol. from total consumption of network segment), in case of biomethane deficit – regional network operates in same conditions as before connection of biomethane plant (but with same specific volume limits – 70% vol. biomethane from total consumption). The last case, according to TSO, is expected to be very usual, as regional gas networks and respectively gas distribution stations (GRS) and gas distribution substations (GRP) are critically underloaded.

Fig 2.17 − Views of TSO on biomethane plants connection to regional and transmission networks

The TSO is considering the creation of so-called “biogas decentralized local distribution networks” to connect several plants in one geographical area and then installation of boosting compressor station and purification equipment for the series of biogas plants. This local biomethane bushes may then be linked to the local consumers (which may be disconnected from the transmission pipeline). Such local networks in some extent are analogical to the current gas extraction infrastructure, which insert gas to the GTS on same principles. The examples of biogas local networks are typical for EU-28 and also there are some cases in Ukraine (Ladyzhyn biogas complex in Vynnytsya region).

The TSO is already developing the pilot project of for biomethane production on Krasnopiliya compressor station (Zaporizhzhya region), adjacent to GRS Dnipro-7 (see Fig. 2.18). Project concept will be based on the analogical EU-based methanation project Jupiter-1000 (France). The methanation process, as already described, is based on the chemical transformation of H_2 and CO_2 to CH_4. For the particular project case in Krasnopillya, the H_2 will be produced from the water electrolysis (the water is the main resource for compressor station used for cooling for main equipment, so the water supply is already in place), the electricity will be produced on site using additionally installed solar PV on the roof of the infrastructure buildings and from tubo-dethander installation on Dnipro-7 GRS. CO_2 will be extracted either from flue gases of nearby boiler house (located on the site of compressor station) or from air. The resulted methane (biomethane) mixed with H_2 will be inserted either to GTS or used on site for boiler house operation and turbo-dethander operation.

Fig 2.18 – Technical concept of pilot project for biomethane production through methanation process at Krasnopiliya compressor station

As a result, the notable points of connection may be (bottom-up) (Fig 2.19):

1) Individual consumers within "local bushes" with high natural gas demand (large boiler houses, CHPP, heat supply companies, industrial consumers (petrochemical/chemical/fertilizer plants, steel industries, oil and gas refining);
2) GRP/SHRP/GRS with high level of consumption on local network segments ("local bush"), especially with large portion of industrial consumers;
3) Points of network within root-based GRS as the knots of distributional branches from trunk transmission pipeline;

4) Trunk transmission pipelines (any point within defined distance 5-15 km) and transmission CS;
5) PSG entrance points and infrastructure;
6) Debit gas installations.

Connection to individual consumers in case of large and annually stable consumption of the individual enterprise, such connection will be the most priority among others. However, there is not much enterprises with such consumption profiles in Ukraine. Typical case will be non-flexible biomethane production when biomethane plant will integrate its production schedule to the operational regimes of enterprise without any alternatives. Also, the quality of biomethane may be the problem, as it may be not suitable for standard production cycle. At the same time it is the most simple type of connection and does not require compressing of biomethane to high pressures. Usual pressure in the gas pipelines of individual consumers is 0.05-3 (population and heat supply companies) and 3-12 bar (different industries).

Connection to GRP/SHRP is more flexible as in this case biomethane plant is operating for the “local bush” of consumers and does not need to integrate the production facilities for the concrete consumer. However, still, the scale of GRP/SHPR is small and gas distribution schedule is also dependent on different consumer schedules. The maximum capacity of “local bush” is higher than for individual consumer. In this case the compressing is needed for 0.05-3 bar, in some rare cases up to 6 bar (when GRP/SHRP is working on industrial enterprises).

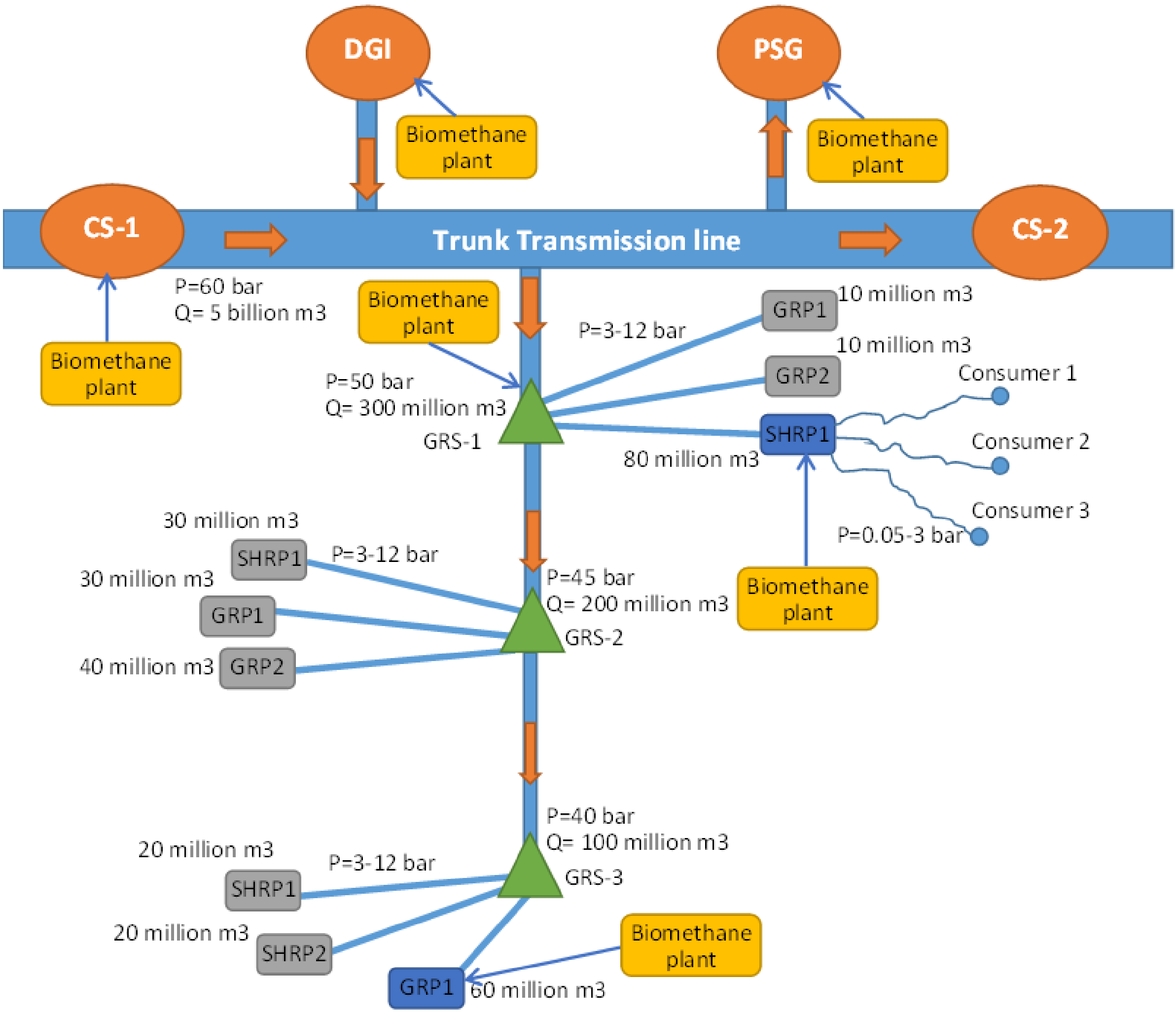


Fig 2.19 − Principal scheme of gas network structure and notable connection points for biomethane plants with indication of typical pressure and consumption on each segments.

Connection to root-based gas distribution stations (GRS), which are formally the part of GTS under operation of TSO is much more flexible than previous two ones. The “local bush” of consumers is several times higher (5-100 times in comparison with individual GRP), flow capacity and consumption is higher and the schedule of gas distribution is more uniform. The problem is that the pressure in such distribution networks may be up to 65 bar, usually in range 30-50 bar, which requires installation of boosting compressing station within biomethane complex.

In case of connection to compressor stations and PSG, biomethane plant in fact in granted with the access to the whole transmission network of Ukraine, which itself could operate as large consumer. The entrance pressure on CS/PSG is usually in range 60-65 bar. This compressors on CS/PSG may pressurize biomethane from entrance pressure of 25-40 bar to 60-65 bar so that biomethane plant may install the same level of compressing equipment then in previous case.

Connection to debit gas installations has the main advantage of the utilization of equipment and infrastructure at this installations. Biomethane plant, in case of the available free network capacity in the point of connection, may be integrated or use the available infrastructure.

Regional analysis of networks capacities for biomethane plants connection

The regional analysis is performed for each region of Ukraine to determine the most priority optimal zones of biomethane plants connection depending on localities with respect to available network consumption capacities. As the macro analysis gives the overview of picture on consumption scale, loads, priority points for large-scale plants, configuration of GRS, distribution of gas general for all Ukraine, the next step is needed to determine all localities influence on consumption bushes as precise as possible with respect to concrete points of gas distribution and consumption, define networks layouts, scale of consumption bushes linked to individual GRP/GRS or their agglomerations, industrial consumers, zones of pipelines linked to individual GRP/GRS.

The general data flow methodology for identification of most priority connection points and then determination of optimal zones for biomethane plants location (mapping of biomethane zones) contain the following steps:

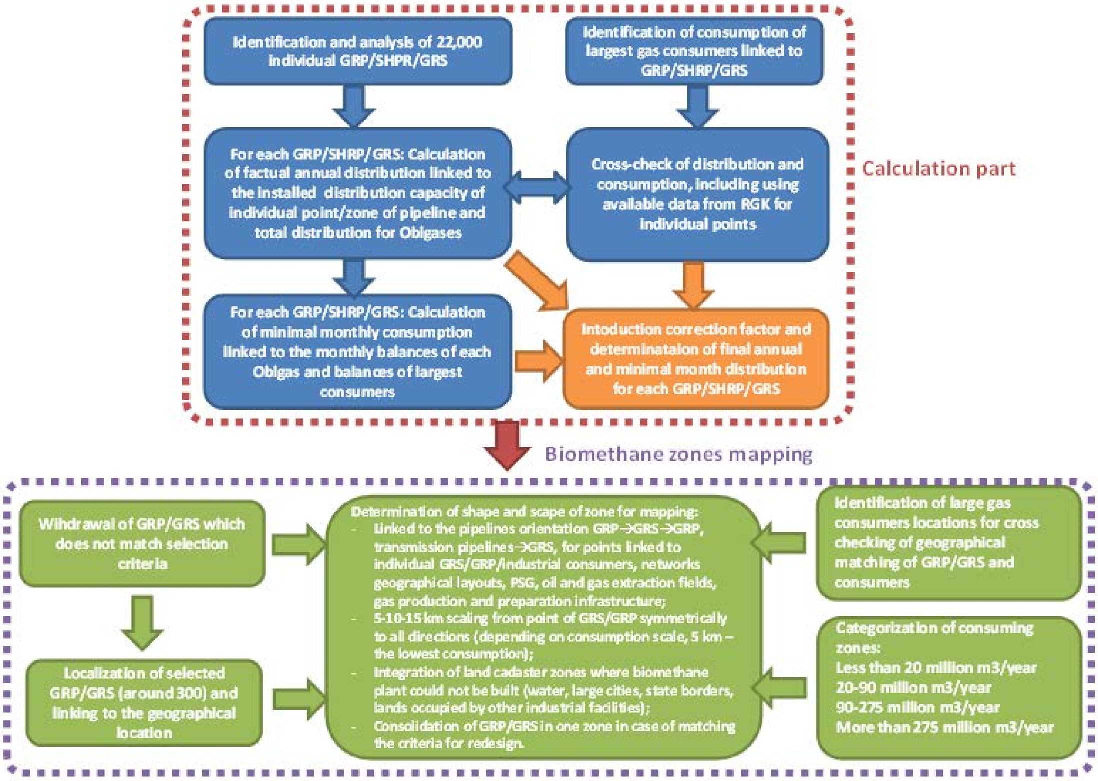


Fig 2.20 − Principal scheme of methodology for identification of biomethane connection points/zones

The results of such analysis are presented on the level for each region, specifying separate points, notable zones of pipelines, industries, agglomerations of consumers suitable for connection (see Annex 2-3 for details).

The integral data for the regions regarding potential connection points/zones is presented in Table 2.2. The main conclusion from this data is that total distribution of selected GRS/GRP is estimated as 22.8 billion nm3/year based on factual annual distribution and 7.2 billion nm3/year (most conservative, based on minimal monthly consumption, i.e. “baseline consumption” stable during all year). The second figure is comparative with the total biomethane potential. At the same time the scale of typical GRP (averaged for all regions for selected most large scale GRP suitable for connection) is 15.5 million nm3/year based on factual annual distribution and 5.9 million nm3/year based on minimal monthly consumption, for GRS (or bushes of several GRPs) – 77.6 and 24.1 million nm3/year respectively. This figures defines the scale for biomethane plant with respect to available consumption in current structure of distribution networks.

The range of GRP capacities varies from 2.0 to 50 (in few cases up to 200) nm3/year, around 65% of all GRPs are within capacity range 5-12 million nm3/year. For GRS capacity varies from 5.5 to 350 (and only few cases higher with absolute maximum of 800 in Cherkasy region) million nm3/year, 50% of all GRS are within capacity range 20-50 million nm3/year. This ranges defines the critical influence of locality and linking to concrete structure/points individually for each network segments, which, in its turn, and due to this conditions the local analysis (Annex 2-3) has been made.

Some of the regions show up the highest identified integral potential for connection and also the most dense, developed and loaded gas grid network with respective infrastructure, for example – Kyiv, Poltava, Kharkiv, Cherkasy, Dnipropetrovsk, Donets'k, Zaporizhzhya, L'viv, Ivano-Frankivsk. These regions also have highly concentrated consumption per individual consumption bush. They are seen as the most priority regions for biomethane plants construction.

Table 2.2. Integral indicators for regions with respect to potential biomethane connection points/zones

Region	GRP					GRS				
	Integral distributon for region, million m3/year	Integral distribution min. monthly ths. m3/month	Virtual annual distribution based on minimal monthly, million/year	Average annual GRP scale million m3/year	Average min. monthly GRP scale, ths. m3/month	Integral distributon for region, million m3/year	Integral distribution min. monthly ths. m3/month	Virtual annual distribution based on min. monthly, million/year	Average annual GRS scale, million m3/year	Average min. monthly GRS scale, ths. m3/month
Vynnytsya	140.2	2,754.9	33.1	10.8	211.9	399.9	6,200.5	74.4	26.7	413.4
Chernihiv	142.3	5,127.0	61.5	23.7	854.5	613.0	18,017.0	216.2	68.1	2,001.9
Khmelnytskyy	46.1	1,086.0	13.0	5.1	120.7	524.0	10,655.0	127.9	47.6	968.6
Zhytomyr	32.9	1,309.0	15.7	6.6	261.8	310.0	9,829.0	117.9	38.8	1,228.6
Kirovohrad	88.3	4,510.0	54.1	11.0	563.8	309.0	11,025.0	132.3	51.5	1,837.5
Zakarpattya	77.7	2,073.0	24.9	11.1	296.1	243.0	5,794.0	69.5	34.7	827.7
Rivne	44.6	679.7	8.2	7.4	113.3	658.8	17,073.2	204.9	109.8	2,845.5
Chernivtsi	93.0	2,618.3	31.4	13.3	374.0	135.0	2,375.0	28.5	33.8	593.8
Ternopil’	66.6	1,794.1	21.5	16.7	448.5	527.5	9,592.0	115.1	37.7	685.1
Iv.-Frankivs’k	82.0	1,750.0	21.0	27.3	583.3	452.5	9,822.0	117.9	37.7	818.5
Kyiv	2,066.3	129,169.0	1,550.0	36.3	2,266.1	4,408.0	102,160.0	1,225.9	259.3	6,009.4
Kherson	11.4	190.0	2.3	5.7	95.0	238.0	5,121.0	61.5	47.6	1,024.2
Sumy	50.9	1,206.0	14.5	17.0	402.0	551.7	12,509.0	150.1	39.4	893.5
Zaporizhzhya	556.9	26,136.0	313.6	42.8	2,010.5	793.0	32,140.0	385.7	72.1	2,921.8
Mykolaiv	176.1	3,289.0	39.5	17.6	328.9	636.5	14,903.0	178.8	90.9	2,129.0
Cherkasy	133.9	2,853.0	34.2	19.1	407.6	1,126.8	25,433.0	305.2	102.4	2,312.1
Odesa	-	-	-	-	-	985.0	29,173.0	350.1	89.5	2,652.1
Volyn	73.4	1,181.0	14.2	9.2	147.6	222.4	4,238.0	50.9	27.8	529.8
Kharkiv	141.8	4,729.0	56.7	20.3	675.6	2,011.0	73,635.0	883.6	125.7	4,602.2
Poltava	109.5	2,345.0	28.1	18.3	390.8	1,325.0	34,737.7	416.9	82.8	2,171.1
L’viv	28.0	864.0	10.4	5.6	172.8	1,034.8	13,775.0	165.3	60.9	810.3
Dnipropetrovs’k	66.2	1,919.0	23.0	13.2	383.8	2,956.0	94,905.0	1,138.9	140.8	4,519.3
Donets’k	124.1	2,520.0	30.2	17.7	360.0	2,375.0	56,750.0	681.0	158.3	3,783.3
TOTAL:	**4,352.2**	**200,103.0**	**2,401.2**	**15.5**	**498.6**	**22,835.9**	**599,862.4**	**7,198.3**	**77.6**	**2,025.2**

<u>Mapping of biomethane zoning with respect to consumption</u>

On the basis of analysis of gas consumption for points/zones/bushes/agglomerations of GRP/GRS, individual consumers according to prescribed methodology on the level of each region of Ukraine, the interactive map of priority zones for biomethane plants location with respect to available consumption capacity for connection to networks has been developed.

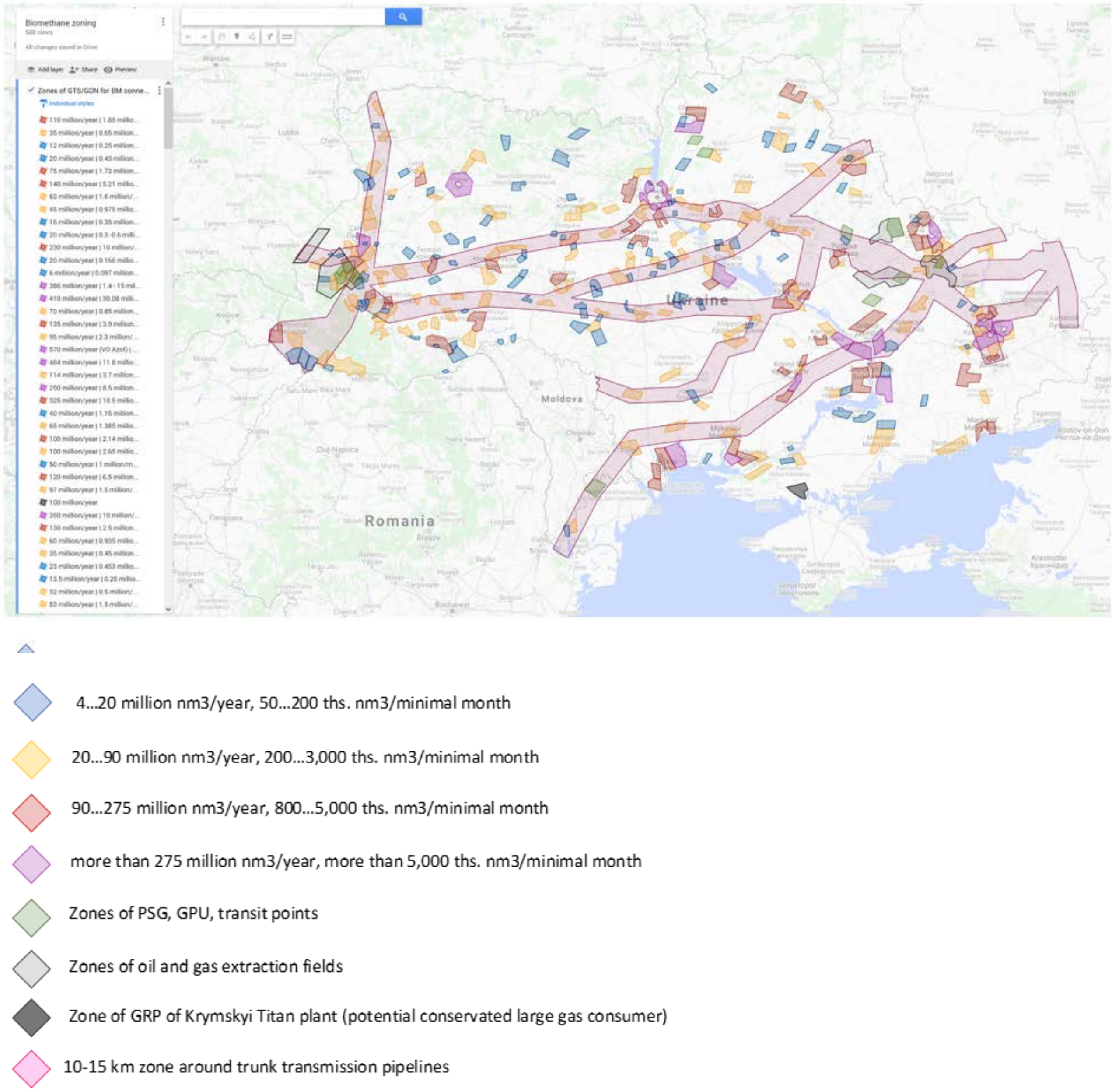


Fig 2.21. Interactive mapping of priority zones for biomethane plants location with respect to local network segments capacities available at:
https://www.google.com/maps/d/u/0/edit?mid=1ttZ12uWjd2NxxH-xc3Lin61fN_4JrE1D&usp=sharing

The map includes more than 300 zones all over Ukraine, ranged according to annual consumption and minimal monthly consumption for each zone. Also, the zone around transmission network (10-15 km distance) without linking to any consumption has been shown (pink color), as well as zones of PSG and oil/gas extraction fields.

The basic conclusions from the map are the following:

1) Total connection potential for defined zones is accounted as 8.7 billion nm3/year (or 200 million/minimal month (2.4 billion nm3/year based on minimal month consumption);
2) The breakdown of zones of gas consumption with respect to scale and geographical form is extremely non-uniform over Ukraine and extremely high linkage to the local conditions of each consumption zone/balance of consumers/character of consumption/geographical orientations;
3) The smallest consumption zone is 2.7 million nm3/year, the largest – 800 million nm3/year;
4) Highest consumption zones are concentrated adjacent to large industrialized cities (Kharkiv, Dnipro, Cherkasy, Odesa, Donetsk region industrial agglomeration, Kyiv), around encircled segments of GRS branches and GRP distribution networks (Rivne, Kyiv, Khmelnitsky, Ivano-Frankivsk and L'viv regional circles) as well as individual regional industrial parks/individual enterprises;
5) Large scale concentrated consumption zones (2-5 enormous consumption zones linked to industry and population agglomerations and small consumption zones linked to small cities/industries, almost without "layer" of mid consumption) with highest average annual consumption per single bush on GRS/GRP (typically more than 50-100 million/year) are located in industrialized and large-populated agglomerations (Dnipro, Kharkiv, Donetsk, Zaporizhzhya, Odesa, Cherkasy, L'viv, Kyiv regions); for other regions (mostly central and western Ukraine) smaller scale decentralized (more or less equivalent distribution between large- mid- and small consumption zones scale) but at the same time more dense zones breakdown (10-50 million/year per single consumption bush) is more typical.
6) The lowest consumption concentration is observed in Kirovohrad, Cherkasy northern part of Mykolaiv and Odesa regions and northern part of Volyn, Rivne, Zhytomyr, Kyiv regions (Polissya zone).
7) The consumption in minimal month (mostly summer time) is crucial parameter defining the scale of biomethane plant; for all 300 zones in average the ratio of monthly minimal consumption and annual consumption accounts as 1/44 (i.e. if annual consumption is 10 million/year, average minimal monthly is 227 ths./month, this could be used for approximate estimation), for zones with large portion of industrial consumers this ratio factor varies between 1/14 to 1/36, for other zones (large portion of district heating or rotational industry (like elevators, farming, grain drying, grain terminals, ports, sugar plants, etc.), the factor varies between 1/36 to 1/76 (in some rare cases for the smallest zones or settlements as 1/100).

Biomethane plant connection schemes to gas networks

The defined consumption zones are mostly linked to clearly identified GRP/GRS which stipulates the necessity of development of preliminary connection schemes on the GRP/GRS level.

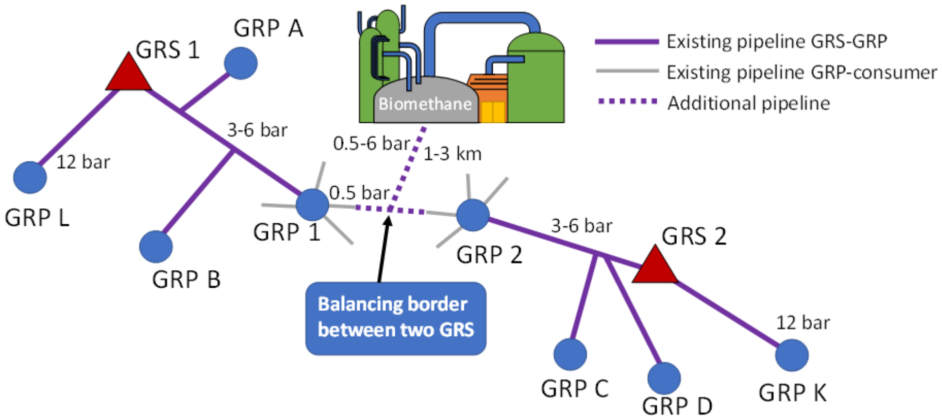
Connection schemes are developed on the basis of patterns for typical layouts of gas networks segments on different regions of Ukraine defined on the previous stage as well as the propositions of RGK linked to the concrete zones of managed distribution networks for connection of several existing biogas complexes in Ukraine (see Annex 2-4).

The range of pressure indicated on the schemes does not mean the "pressure fluctuations" in networks operations. The networks segments usually operates within defined levels of pressure without fluctuations according to hydraulic balance of each segment. The range of pressure on schemes here represents the variety of pressure levels in different network layouts which may be found in different locations. In other words, the similar typical network layouts may have different pressure levels in different locations.

Scheme #1: Connection to balancing border between two GRS

Proposition for connection (RGK): Teofipol biogas plant

The essence of the scheme is connection between two points – where the balancing borders (end-line GRPs or distribution networks from GRS to end consumer) of two adjacent GRS are geographically located as close as possible. In this case, the additional pipeline shall be designed for connection of two border points between each other (with hydraulic recalculation) and for connection of biomethane plant to any place between the two border points. The layouts of networks in some zones are represented by such a structure of networks orientation with typical distances of 1-3 km between two points. The biomethane plant in this case will produce biomethane for the consumption bush of two adjacent connected GRP #1 and GRP #2 (0.5 bar low pressure networks) or two adjacent GRSs (average pressure to high 2nd cat. pressure networks 3-6 bar) with agglomeration of GRP # 1, 2, A, B, C, D. Note, that GRP # L, K in current scheme will not be within the consumption bush as they are located beyond the line (on the other branch of GRS).



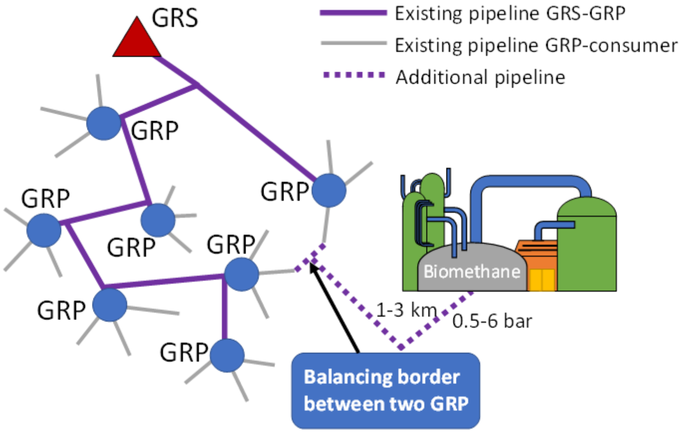
Connection to balancing border between two GRS

Scheme #2: Connection to balancing border between two GRP of single GRS

Proposition for connection (RGK): Teofipol /Josypivka/Horodysche-Pustovarivka biogas plants

The layout of distribution networks in some zones stipulates the orientation of networks in the way where the end-line GRPs from single GRS are close to each other geographically but working for different bush of consumers. In this case the structure of networks is represented by two (or more) different branches from GRS with own bushes of GRPs on each branch, with the common node point at start. At the beginning of branching, the lines are moving further away from each other, and when approaching the end of each line, they are getting closer to each other. The end-line GRPs may be on the distance of 1-3 km between them, while the most far points between branches may be 10-20 km. The connection of this close end-line GRPs creates the closed single circle of GRS consumption bush. The biomethane plant shall be connected between the two end-line GRPs (0.5

bar, operating for two adjacent GRPs) or in any other point of circle (6 bar, operating for all GRS consumption bush).

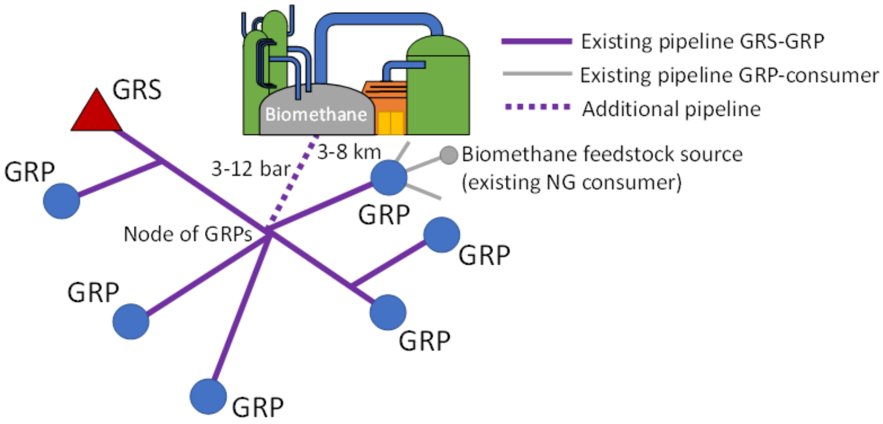


Connection to balancing border between two GRP of single GRS

Scheme #3: Connection to node of several GRPs

Proposition for connection (RGK): Ladyzhyn biogas plant

Another type of structural layout is knotting of several GRPs in one node after several junctions to other GRPs from single GRS. In this case biomethane plant shall be connected to such nodes. This structure is very typical in distribution networks in Ukraine and could be found in a lot of GRS distribution bushes for most regions. Note, that the GRP for the enterprise which is existing natural gas consumer and at the same time provides biomethane feedstock source will be much closer geographically, basically on the same site with biomethane complex. The node will be more far away from biomethane complex but the consumption of gas in node will also be much higher (according to the sample scheme, 5 GPRs on node and 1 GRP for existing biomethane feedstock enterprise). The connection to the node will require increasing of pressure to 3-12 bar (has to be done for GRS-GRP branches, which are average pressure category (3 bar), high pressure 2nd category (6 bar) 1st category (12 bar)) depending on the local conditions. For comparison, the Schemes # 1 and # 2 foresee connection to average and low pressure lines GRP-end consumer (0.5-3 bar). Increasing to 6 bar is needed only to inject biomethane from lower segment of GRP-GRS line or GRP-consumer line towards higher segments of GRP-GRS line to increase consumption bush.



Connection to node of several GRPs

Scheme #4: Connection to lower segment of GRS-GRP pipeline for reverse injection

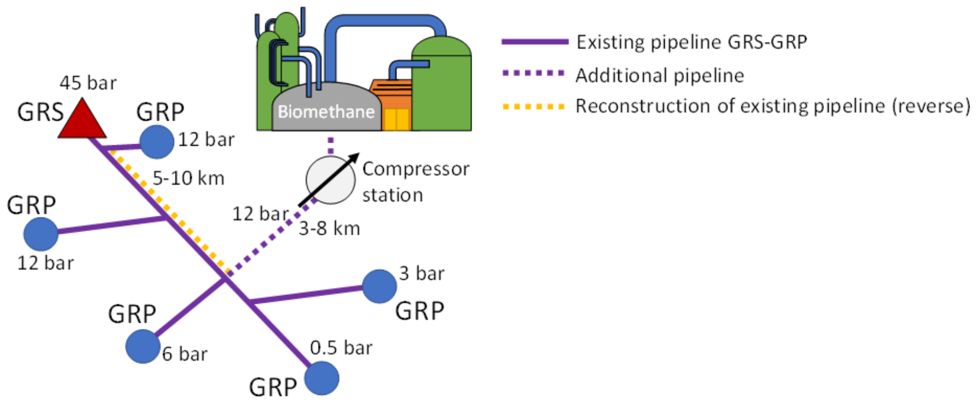
Proposition for connection (RGK): Ladyzhyn/Velyka Dymerka (designed) biogas plant

Covering of all consumption bush of GRS will require either BM plant connection to the point right after GRS reduction (12 bar) or to the point of lower segment of GRS-GRP network. For the second option reverse injection to the upper segments of network (till GRS exit point but not higher) is needed. On practice, biomethane plants location may vary depending on factors other than networks orientation. In case of connection to lower segment of GRS-GRP line, it is necessary to:

1) Install compressor for 12 bar pressurizing to let biomethane flow in any direction witing GRS-GRP branch but not higher than GRS reduction point;
2) Construct additional line from BM plant to closest lower segment point of connection is needed (3-8 km);
3) Reconstruction of upper segment of GRS-GRP line (5-10 km) up to the first node of branching for the first GRP on line.

The #1 and #2 has to be done by the BM plant investor, #3 – by local gas distribution company (Oblgases). The reconstruction of GRP-GRS lines are included as a part of basic reconstruction measures approved by several Oblgases in their Plans of Reconstruction till 2030 or Investment Plans (approved by NERC). Also, this plans may be reviewed in case of concrete demand for connection point for designed BM plant.

Note, that within such connection concept the increasing of pressure for more then 12 bar (for example to 45 bar and more to overpressure GRS and inject biomethane higher along the network towards high pressure trunk branches “transmission pipeline-GRS” for agglomeration of GRSs) is not considered, though it is possible. This case in described below for separate connections schemes #5a, #5b. This unbundling of two principally different concepts of connection schemes is done on purpose to follow the principle of scale equivalency for biomethane complex and respective consumption bush (the higher is the capacity of biomethane plant, the higher shall be the point of connection along network).



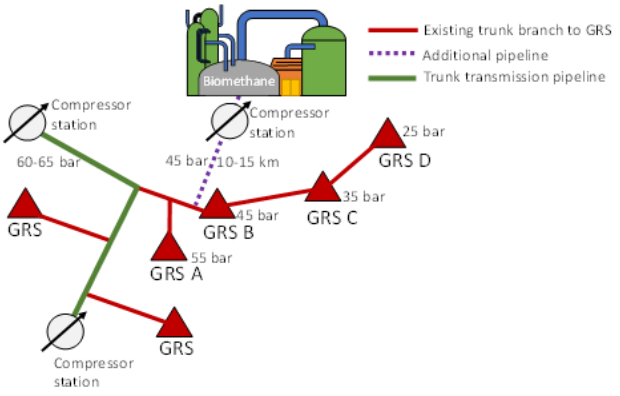
Connection to lower segment of GRS-GRP pipeline for reverse injection

Scheme # 5a, 5b: Connection to trunk transmission pipelines and GRS branches

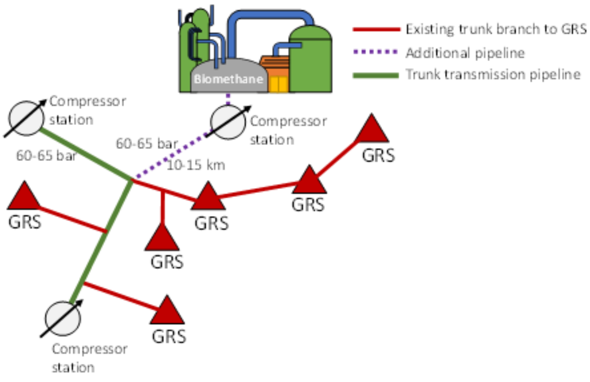
Direct connection to transmission pipelines has to be done for large-scale (more than 20 million nm3/year) biomethane plants if any kind of other connection schemes are not available. Such connection shall foresee installation of own boosting compressor station within biomethane complex and construction of additional high-pressure pipeline from BMC to point of connection (costs to be covered by investor).

For Scheme 5a – the connection shall be done at the closest root-based point of branch from trunk pipeline to GRS agglomeration right after pressure drops to 45 bar and below. According to the network's layout, this point may be after several junctions to other GRS agglomerations (after GRS #A on the scheme). Also, the branch itself can operate at 45 bar (or lower) pressure from first GRS to end-line GRS. The scale of consumption of such GRS agglomerations (GRS #B, C, D according to scheme) is at least 30 million nm3/year with minimal monthly consumption at least 600 ths. nm3/month, typically much higher (average 100 million/year and 5 million nm3/ minimal month, maximum up to 1.5 billion/year and 20 million nm3/ minimal month). So, this connection shall be considered for large scale biomethane plants (from 20 million nm3/year and more).

For Scheme 5 b – the connection shall be done at any point of trunk transmission pipeline provided by TSO (preferably directly in-between two existing compressor stations on transmission line with symmetrical distance from both or directly to the compressor station using local infrastructure). The consumption in this case is basically limited to capacity of current segment of network (which even for transmission networks of lowest capacity is several times higher than the most large-scale feasible biomethane plant). However, such points are linked to the zones where transmission networks are laid which decreases the flexibility of localization of BMC. Also, the highest and most expensive pressurizing of biomethane is needed (60-65 bar) in conjunction with additional network from BMC to transmission pipeline. Due to such additional large expenditures and linkage to the network location, only the largest scale biomethane plants may be considered as candidate for such connection.



Scheme 5a: Connection to GRS branch 45 bar



Scheme 5b: Connection to trunk transmission pipeline

Standard procedure for connection of biomethane plant to distribution networks

Connection to the gas distribution network of objects, customers or existing facilities is carried out in accordance with the Code of gas distribution systems[6], approved by the resolution of the NERC №2494 from 30 September 2015.

The Code of Gas Distribution Systems distinguishes between two types of connection: standard and non-standard.

Standard connection

- capacity of gas consumption facilities up to 16 nm3/hour;
- the distance from the point of gas supply to the connection point of network is not more than 10 meters in urban areas or 25 meters in village zones.

Non-standard connection:

The service is available for consumers whose capacity of gas consumption facilities is more than / equal to 16 nm3/hour or the distance from the gas supply point to the connection point is more than 10 meters in urban areas and 25 meters in rural areas or on the customer's land plot.

To connect gas supply facilities to gas networks, the customer must:

- apply to local regional gas distribution company (Oblgas), in the relevant district department which operates gas networks;
- submit a written application for connection of the customer's facility to the gas distribution system;
- submit a package of documents, including:

- completed questionnaire according to the form approved by local gas distribution company, which indicates the technical parameters of the customer's facility to be connected to the gas distribution system.

[6] https://zakon.rada.gov.ua/laws/show/z1379-15#Text/

- copies of documents that determine the right of ownership or use of the customer for the object (premises), and / or a copy of the document confirming the right of ownership or use of land (with a graphic plan of the land plot).

- copies of customer documents which certify an individual or his representative (for individuals), certifying the status of a legal entity or a physical person – entrepreneur (FOP) and its representative (for legal entities and natural persons - entrepreneurs), registration with the State Fiscal Service in accordance with the requirements of the Tax Code of Ukraine.

The Connection Agreement and technical conditions of connection come into force from the date of their submission by customer (signed) in regional gas distribution company or the relevant district gas management utility, and after payments of services for permission to connect to network, the Connection Agreement concordance and technical conditions for connection, if it is provided by the current legislation.

After concluding the Connection Agreement, regional gas distribution company ensures the connection of the customer's facility or land plot (construction of external gas supply networks from the place of power supply to the connection point) within three months, taking into account the requirements of the Gas Distribution Systems Code and the customer payment schedule.

Compressor stations for biomethane injection to gas networks

The compression of biomethane is needed in case of pressurizing and injection to trunk transmission pipelines, GRS and its branches. For injection to transmission pipelines, the inlet pressure shall be 60-65 bar, for branches/GRS – 40-45 bar. The end-line (impasse) GRS or branches zones may have pressure of 20-25 bar, while the root-based GRS/branches zones may have same pressure level as trunk pipelines (60-65 bar). Also there is a case of implementation of reverse-pressurizing concept when the pressure in branches is lower (40 bar), while inlet biomethane pressure is specially made higher (65 bar) to let biomethane flow towards trunk transmission pipeline in case of lack of GRS/branch consumption.

The case of pressurizing from 1 to 3, 6, or 12 bar (distribution networks) is not considered here because the compressors for such scale are serially produced and are available on demand without any commercial propositions (this is more domestic-like compressors for local pressurizing purposes), while in this section we consider only industrial-scale compressing equipment which is made individually (on order) depending on concrete requirements/parameters of customer.

For all cases, the parameters for compressor station[7] needed for biomethane pressurizing and injection to gas pipelines may be generalized as follows:

Option 1:

[7] The term "Compressor station" is used as it includes compressor and all auxiliary equipment, such as engine driving unit (reciprocating/electric engine/turbine), automatics, filters, container, noise suppression unit, cooling/heating equipment, valves, vents, pipeline complex, emergency system, connection to on-site communications, gas reduction system, spare parts and others. The respective costs of single compressor and compressor station differs in 2-10 times (the less is the scale, the more is the difference).

Injection to trunk transmission pipelines and/or reverse-pressurizing concept branches→trunk pipelines:

Annual biomethane flow rate: 50 million nm3/year

Hourly flow rate: 6,000 nm3/hour;

Inlet pressure: 1-3 bar, Outlet pressure: 60-65 bar;

Option 2:

Injections to trunk pipeline branches/GRS:

Annual biomethane flow rate: 10 million nm3/year

Hourly flow rate: 1,200 nm3/hour

Inlet pressure: 1-3 bar, Outlet pressure: 40-45 bar

Option 3:

Injection to end-line (impasse) of branches/GRS:

Annual biomethane flow rate: 10 million nm3/year

Hourly flow rate: 1,200 nm3/hour

Inlet pressure: 1-3 bar, Outlet pressure: 20-25 bar

For all options the compressor station models suitable for mentioned parameters is represented by wide range of producers, the main are: Siemens, Elliott Group, GPE Turbo (DE), Bauer GRU™ HP, Gardner Denver, SIAD Machine Impianti (for biogas and biomethane), Ventos, Danfoss, Ariel, Poltava turbo-mechanical plant (PTMZ) and many others.

Gardner Denver

Bauer GRU™ HP

Ventos

GPE Turbo

As for the basic compressing technology applied, for Option 2 and 3 the piston-based compressing is most suitable (single or multi stage (10 bar each stage pressure increase), for Option 1 – piston-based, centrifugal, screw or combined and multi stage schemes.

According to the market analysis, namely approximation of capital costs of large-scale centrifugal turbo-compressors on trunk pipelines to the prescribed scale, available information on reconstruction and new compressor installation published in Plans of Reconstruction of TSO, data on lots for new compressors and compressor stations on ProZorroUA, commercial offers from suppliers, the following capital costs for compressor stations for each Option can be specified:

Option 1: **2.5-3.0 million Euro** (centrifugal, piston or combined multi-stage schemes)

Option 2: **0.5-1.5 million Euro** (piston container type multi and/or one stage schemes)

Option 3: **0.25-0.8 million Euro** (piston only, one-stage scheme).

The capital costs for small-scale compressors (from 1 to 3, 6, 12 bar) for the mentioned flow rate are estimated as 30-80 ths. EUR according to publicly available prices in retail network (10 times less than Option 3).

As for the annual operational costs, there is crucial dependence on concrete set and combinations of equipment chosen, however for rough estimation the specific indicators are 10% from CAPEX for piston-engine based compressing and 5% from CAPEX for other technologies (excluding fuel costs).

Measures addressing issues of low minimal monthly consumption

As mentioned many times before, the minimal monthly consumption of local bush is often the crucial limitation factor for choosing the scale of biomethane plant. However, there are practical project cases, where minimal monthly consumption issue may be mitigated as biomethane plant is linked to the existing enterprises with local natural gas consumption or infrastructure where biomethane could be utilized locally without necessity of pressurizing ore rebuilding network infrastructure. We consider the following cases which can mitigate the problem of monthly low consumption:

1) Planned zones of redesign (including encircling with consolidation of several small bushes in one larger scale bush with abandoning of most far, small-scale and non-effective distribution facilities) of gas distribution networks by regional gas supply companies and trunk branches by TSO bearing in mind, among others, the new criteria of biomethane potential and concrete sites for biomethane complex constructions.

2) Large-scale agroholdings clusters in Ukraine of 20-50 ths. ha (geographical layout equivalent to geometrical circle on landscape with 10-20 km radius)[8]. The specific biomethane production from 1 ha of corn residues is assessed as 4 ths. nm3/year with 100% residues removals and 1 ths. nm3/year with 25% average for cluster residues removals (or equivalent 25% of area used for silage cultivation, for example). For the mentioned cluster scale this mean that capacity of a single biomethane complex linked to the respective cluster as 20-50 million nm3/year. Due to geographical scale, locations and forms of agro clusters, at least either one zone of equivalent biomethane consumption bush (including industrial consumers

[8] See for example, Kernel (largest agroholding in Ukraine in 2021) clusters mapping : https://www.kernel.ua/about/

with close-to-base consumption profile) or at least segment of trunk transmission pipeline is within the zone of each of agro cluster. Also, the agro clusters themselves are the consumers of natural gas (especially in summer minimal gas consumption) due to available infrastructure (agro processing, elevation, logistics, transport vehicles);

3) Consumption of transport vehicles on gas filling stations which is higher in summer period than in any other period during year;

4) Poultry farms (up to 10% from total biomethane potential) have the summer (minimal) basic rated heat load (output) for production purposes (butchery, incubators, factories for compound feed production) on level of 0.5-1 MW(th)/500 000 poultry units. If the average scale of poultry complex in Ukraine is estimated as 2-3 million heads, then equivalent natural gas consumption (base load) is 450 ths. nm3/month. For the largest poultry complexes (for example, Ladyzhyn, Oril (Elyzavetivka)), this indicator may be up to 1.5 million nm3/month[9]. These demand levels could cover the production of biomethane and are comparative with the average biomethane installation scale according to criteria specified above.

5) Introduction of combined schemes (combination of production of biomethane, electricity, heat, CO_2) in months of minimal consumption (mainly for existing plants) or, where applicable, installation of local week-level gas storage);

[9] https://mhp.com.ua/uk/pro-kompaniiu/tov-vinnicka-ptahofabrika-prat-mhp

Analysis of the technical capabilities of transition and distribution gas pipelines to receive biomethane:

The ways of biomethane production

Biomethane can be produced in three main ways:

1. Microbiological fermentation of organic material with a low content of lignocellulosic complexes (LCC), mainly from agriculture raw materials and waste, the organic fraction of MSW, sewage sludge in controlled bioreactors to produce biogas and its subsequent purification from impurities and increasing methane content;
2. Collection of biogas at landfills and waste dumps with subsequent purification from impurities and adjusting to the quality of NG;
3. Biomass gasification (with high LCC content mostly wood) to produce synthesis gas (mixture of hydrogen, methane and carbon monoxide) with its subsequent methanization, purification and quality adjustment to NG.

Biogas is composed mainly of CH_4 and CO_2 (up to 98-99% in total) and impurities (0-2%). Depending on the type of raw materials and involved technology biogas can differ substantially. That largely determines the technology of its upgrading to biomethane. Table 3.1 shows the comparative characteristics of biogas from different sources.

Table 3.1. – Composition and characteristic of landfill gas (LFG) and biogas from manure [1]

Parameter	Units	LFG	Biogas from manure
Lower calorific value	MJ/nm^3	16	23
	kWh/nm^3	4,4	6,5
	MJ/kg	12,3	20,2
Density	kg/nm^3	1,3	1,2
Wobbe index	MJ/nm^3	18	27
Methane number	-	> 130	>135
Methane (variation)	vol-%	45 (35–65)	63 (53–70)
Carbon dioxide (variation)	vol-%	40 (15–50)	47 (30–47)
High hydrocarbons	vol-%	0	0
Hydrogen	vol-%	0–3	0
Carbon monoxide	vol-%	0	0
Nitrogen (variation)	vol-%	15 (5–40)	0,2
Oxygen (variation)	vol-%	1 (0–5)	0 (0–1)
Hydrogen sulfide (variation)	ppm	< 100 (0–100)	< 1000 (0–10000)
Ammonia	ppm	5	<100
Total clorine (based on Cl^-)	mg/nm^3	20–200	0–5

[1] M. Persson, O. Jönsson, A. Wellinger. Biogas upgrading to vehicle fuel standards and grid injection. – IEA Bioenergy. Task 37 - Energy from biogas and landfill gas. – December 2006.

An important LFG feature is the probability of increased content of nitrogen, oxygen, sulfur, chlorine, siloxanes. Biogas from agriculture waste differs by increased content of hydrogen sulphide and ammonia, in turn siloxanes[2] in agriculture biogas are practically not present.

Methods of biogas upgrading

There are three main reasons why upgrading of biogas is needed:

- Ensure compliance to the properties of fuel used in various types of equipment (engines, boilers, fuel cells, etc.);
- Increase caloric value;
- Standardization of gas fuels.

Methods of biogas upgrading depend on method of following utilization. For example, for heat production in the boiler restrictions apply only H_2S concentration (1000 ppm). Thus there is no need to remove moisture and carbon dioxide. In case of biogas cookers there are higher requirements for cleaning of H_2S. For biogas combustion in reciprocating engines, there are certain requirements for the content of H_2S (generally no more than 200 ppm) and siloxanes, and excessive moisture content (no condensation allowed). The most stringent requirements for biogas cleaning imposed in the case of supply to NG grid and direct use as a motor fuel.

The main target component for removal in biogas upgrading is carbon dioxide. Technology for its removal is crucial in the overall scheme of purification. Additional purification steps are pre-or post-removal of impurities, mainly H_2S, moisture, siloxanes, and possible correction of BM to the dew point temperature and the calorific value depending on the requirements of the applicable standard. An important component of the scheme is to clean flue gas discharge to the atmosphere.

Biogas enrichment sorption, filtration and cryogenic techniques are main parts of the used technologies. There are next major commercial technologies of biogas upgrading:

- Pressure swing adsorption (PSA).
- Absorption of water (water scrubber).
- Organic physical scrubber
- Chemical scrubber.
- Membrane separation.
- Cryogenic separation.

Pressure swing adsorption

The essence of the method consists in sorption of CO_2 molecules on the surface of materials under high biogas pressure. Activated carbon or molecular sieves are usually used as sorbent material. The process removes also O_2 and N_2. Regeneration held by stripping under reduced pressure. In this method, moisture and the H_2S should be removed at the preliminary stage.

Water scrubber

[2] Siloxanes are a subgroup of silicones containing Si-O bonds with organic radicals

Solubility CH_4 in water is lower by factor 25-74 than solubility of CO_2 and H_2S, respectively (P = 101.325 Pa, T = 20° C) [3,4,5]. This physical feature is the basis of the method of gases separation by absorption in the water scrubber at elevated pressure (5-10 bar). Desorption of CO_2 and H_2S from the water takes place when the pressure reduces to atmospheric pressure or lower. To intensify desorption the air is used. To prevent fouling of water circulation system it is recommended to remove H_2S in the preliminary stage. Water vapor is removed after the upgrading stage. A feature of this technology is the need to control the content of O_2 after air stripping.

Organic physical absorption

Some organic substances capable of absorbing CO_2 and H_2S more active than water. As such adsorbent usually used polyethylene glycol (e.g., trademarks Selexol® and Genosorb®). Basic processes for this case are similar to the water scrubber technology. Hydrogen sulfide is recommended to remove at a preliminary stage, since the organic sorbent regeneration requires a significant amount of energy.

Chemical scrubber

Other organic substances have the ability selectively bind CO_2 at low pressure. In chemical scrubber group of amines (monoethanolamine, dimethylethanolamine) are used. This method has a high degree of removal of CO_2 with little loss of CH_4. Regeneration of the sorbent takes place by the reverse chemical reaction is usually initiated by heating and/or vacuuming. Hydrogen sulfide is removed in a preliminary step. After upgrading, biomethane dried and compresses.

Membrane separation

Membrane separation is of two basic types: "gas-membrane-gas" ("dry" membrane) and "liquid-membrane-gas" ("wet" membranes). Dry membranes are based on the creation of a pressure difference on both sides of the membrane, wherein the gas molecules (CO_2 and H_2S) pass through the membrane pores, and CH_4 molecules do not. Dry membranes operate at high (> 20 bar) or medium pressure (8-10 bar). In case of wet membranes absorbents (amines) absorbing CO_2, which diffuses through the membrane are used. The process takes place in low excess pressure close to atmospheric. Before upgrading biogas is compressed and dried. After separation requires additional cleaning from H_2S.

Cryogenic separation

The boiling temperature of methane is -161,5 ° C, and carbon dioxide -78,5 ° C. With decreasing temperature and overpressure condition CO_2 becomes liquid when methane is still in gaseous. In this CO_2 can be relatively easily separated from the methane. CO_2 in this case is sufficiently pure and can be used as commercial product. Moisture and hydrogen sulfide should be removed in advance.

Removal of hydrogen sulfide (H_2S)

For H_2S removal biological, chemical and physico-chemical methods are used. In biochemical desulfurization excessive amounts of O_2 and N_2 can stay in biogas that should be considered when

[3] *R. Crovetto*, Evaluation of Solubility Data for the System CO2-H2O, J. Phys. Chem. Ref. Data, 20, 575, 1991.
[4] *P. G. T. Fogg and C. L. Young, Eds*., IUPAC Solubility Data Series, Vol. 32, Hydrogen Sulfide, Deuterium Sulfide, and Hydrogen Selenide, Pergamon Press, Oxford, England, 1988.
[5] H. L. Clever and C. L. Young, Eds., IUPAC Solubility Data Series, Vol. 27/28, Methane, Pergamon Press, Oxford, England, 1987.

selecting the technology of biomethane upgrading. In this regard, other techniques such as the catalytic conversion of the sulfur in the surface of the activated carbon or the exchange reaction with the oxide/iron hydroxide to form FeS, in some cases more preferred.

Removal of oxygen (O_2) and nitrogen (N_2)

In biogas enrichment technologies such as PSA and membrane separation, oxygen and nitrogen, to a certain extent removed simultaneously with CO_2.

Dewatering

Biogas after reactor or landfill has a relative humidity of 100%. Water vapor content depends on temperature and equals 40 g/nm^3 at 35^{o}C. A typical way of removing moisture from the biogas is vapor condensation at low temperatures. To raise the temperature of "dew point" before cooling further increases the pressure of biogas.

In case of biomethane use as motor fuel "dew point" should be below -40°C under a pressure of 4 bar. In this case, further water vapor adsorption on the surface of a drying agent (silica or alumina) is used. The adsorption is carried out at overpressure, after which the drying agent is regenerated when the pressure decreases.

Another way to reduce "dew point" may be the absorption of water in the glycol or hygroscopic salts. Desorption of the water occurs at higher temperatures. Salt should be replaced.

Siloxanes removal

Siloxanes removed by activated carbon. Carbon cannot be recovered and requires replacement. Another method is absorption in a liquid solution of hydrocarbons.

Table 3.2 shows the comparative characteristics of upgrading technologies discussed in terms of biogas needs in energy and material resources, as well as the main process parameters.

Table 3.2 – Comparison of biogas upgrading methods[6]

		PSA	Water scrubber	Organics physical scrubber	Chemical scrubber	Membrane separation	Cryogenic separation
Electricity demand	kWh/nm^3 of biogas	0,2-0,25	0,2-0,3	0,23-0,33	0,06-0,15	0,18-0,25	0,18-0,33
Heat demand	kWh/nm^3 of biogas	0	0	~ 0,3	0,5-0,8	0	0
Temperature	°C	-	-	55-80	110-160	-	-
Pressure	bar	4-7	5-10	4-7	0,1-4	5-10	
Methane loss	%	1-5	0,5-2	1-4	0,1	2-8	
Flue gas cleaning (Requirement of EEG and GasNZV standards)		yes	yes	yes	no	yes	yes
Additional H_2S cleaning		yes	no	no	yes	recom.	yes
Water consumption		no	yes	no	yes	no	no
Chemical reagents consumption		no	no	yes	yes	no	no

[6] Biomethane / FNR, 2013

Technical barriers to biomethane injection in the natural gas grid due to non-zero content of oxygen

In LFG along with nitrogen oxygen can be taken from air infiltration through the landfill. Oxygen promotes corrosion and biofouling in gas storage facilities. The procedure for purifying biogas from hydrogen sulfide by supplying air to the under-dome space of the reactor could also be potentially a source of oxygen in biogas. The O2 content in crude biogas may be 0.1-1.0 mol.%)[7].

Priority in the case of the production of biomethane is the maximum reduction in oxygen ingress into biogas, what is achieved by control of air intrusion in LFG collection systems and using appropriate methods as raw biogas pre-treatment.

Currently available and widespread in the world biogas upgrading technologies allow to ensure compliance with the requirements of the GTS Code of Ukraine on most indicators, except for the requirement for a maximum allowable oxygen content of O2 not more than 0.02 mol. %. (tabl.3.3)

Table 3.3 –Requirements for natural gas supplied to the gas transmission and gas distribution system of Ukraine, according to the GTS Code

Parameter	Value
Methane content (C1), mol. %	≥ 90
Ethane content (C2), mol. %	≤ 7
The content of propane (C3), mol. %	≤ 3
The content of butane (C4), mol. %	≤ 2
The content of pentane and other heavier hydrocarbons (C5 +), mol. %	≤ 1
Nitrogen content (N2), mol. %	≤ 5
The carbon content (CO2), mol. %	≤ 2
Oxygen content (O2), mol. %	$\leq 0{,}02$
Content of mechanical impurities:	Absent
Hydrogen sulfide content, g / m3	$\leq 0{,}006$
Mercaptan sulfur content, g / m3	$\leq 0{,}02$

This requirement is obviously justified both from the point of view of ensuring safe non-destructive operation of gas transmission / distribution systems of Ukraine, especially in "wet" conditions (for example, in underground gas storage facilities) and from the point of view of technical feasibility of natural gas producers suppling such gas in the gas transmission and gas distribution system of Ukraine. However, compliance with the requirement for O2 content less than 0.02% by biomethane producers may require further complication of technological schemes for biogas treatment and a significant increase in the cost of biomethane per unit of energy. In Ukraine, such an additional increase in the cost of biomethane production may lead to a loss of interest of investors and lack of biomethane sector development.

Limited requirements for the content of O2 in biomethane entering the gas network also exist in the EU countries (Table 3.4). The level of such requirements in most EU countries and at the European level were less strict (0.5-3 mol%) than the requirements of the GTS Code of Ukraine except France. This makes it possible for biomethane to access gas networks in terms of O2 content.

[7] http://task40.ieabioenergy.com/wp-content/uploads/2013/09/t40-t37-biomethane-2014.pdf

Table 3.4 –Requirements for O2 content in biomethane supplied to gas networks in EU countries

Parameter	**Value,** not more than mol. %	
	for «dry» grids	for «wet» grids
Germany	3	0,5
Great Britain	1	
Sweden	1	
Austria	0,5	
Switzerland	0,5	
Denmark	0,5	
France	0,01	
The Netherlands	3	
Standard EU prEN 16723-1	1	0,001

It is possible to see that the requirements for O2 content depend on the dry or wet grid type. Accordingly, for the wet grid the requirements are more stringent, because the combination of oxygen and moisture creates a risk of destruction of pipes, equipment or other structures. In opposite, the presence of oxygen in the dry gas should not lead to problems with biological corrosion of materials.

Standard EU prEN 16723-1 says that biomethane shall meet the requirements of EN 16726 for common parameters including O2. It means that O2 content is regulated by EN 16726.

Standard EN 16726 says that at the points of entry into the network and connection nodes, the molar fraction of oxygen, expressed as a variable average over 24 hours, should not exceed 0.001%. However, in cases where it is shown that the gas is not supplied to structures sensitive to higher oxygen content, such as underground storage systems, a h*igher maximum oxygen content of up to 1% may be applied.*

Understanding the motivation for setting requirements for the composition of natural gas supplied to gas transmission and distribution systems in Ukraine, in particular in terms of the maximum allowable O2 content, we believe that it is possible to consider revising this requirement for biomethane producers and, if appropriate, for all market participants in Ukraine. In our opinion, it would be possible and expedient to introduce the norms of the European standard EN prEN 16723-1 with the norm of O2 content in biomethane supplied to dry NG grid at the level not higher than 1 mol. %.

From the point of view of biomethane logistics, it can be assumed that in the vast majority of cases it will be fed into the gas distribution system, and therefore physically it will not enter underground gas storage facilities with increased risk of biodegradation in the presence of moisture and oxygen.

The cases of direct supply of biomethane to the industry customers sensitive to O2 content as soon as the cases of physical delivery of biomethane across the country border should be investigated individually case by case. It should also take into account the significant dilution of biomethane with natural gas when pumping it into the gas distribution network.

Technical barriers to biomethane injection including the impacts of the biomethane trace components in terms of corrosion

Various components in the biogas can differently effect on subsequent transportation and utilization of biomethane. Table 3.5 shows the main impurities in the biogas and the nature of their influence.

Table 3.5 –Types of admixture in the biogas from different sources and nature of their impact[8]

Admixture type	Source of origin	Impact
CO_2	Carbon mineralization of organic matter	Reduces the overall calorific value, leading to corrosion of the metal parts of the equipment due to the formation of weak carboxylic acid
H_2S	Proteins, manure, organic waste	Leads to corrosion of metal parts, SO_2 emissions from the combustion or H_2S by incomplete combustion, destroys catalytic converters
H_2O		Due to the formation of weak acids with other substances promote corrosion of metal parts; damage instrumentation from airborne condensate; leads to icing accumulated moisture at high pressures and relatively low temperatures
NH_3	Proteins	Leads to an increase in anti-knock properties of the engines; causes the formation of NOx, promotes corrosion
N_2	With air	Leads to an increase in anti-knock properties of the engines; reduces overall calorific value
Siloxanes	Cosmetics, defoamers, detergents (in LFG and sludge)	Because quartz silica particles leads to abrasion of moving parts
Dust	LFG	Leads to clogging in ventilation systems and chimneys

It is reported that the use of siloxanes is increasing in household industrial cleaning products and personal care products. Most siloxanes are very volatile and decompose in the atmosphere into silanoles, which are eventually oxidised into silicon dioxide. Some siloxanes end up in wastewater and are adsorbed onto the extracellular polymeric substances of sludge flocks. Siloxanes are volatilised from the sludge during anaerobic digestion and end up in biogas.

Silicones are also sometimes added in digesters as anti-foaming agents, where they can biodegrade into siloxanes. Also, organic silicon compounds end up in landfills from sources such as shampoo bottles and other containers in which some of the product remains, through landfilling of waste water treatment sludge and from packaging and construction material.

During combustion of biogas/biomethane, siloxanes and other organo-silicon compounds form silica which generates deposits, e.g. on valves, lambda oxygen sensors and cylinder walls, causing abrasion, exhaust gas misalignment or blockage of pistons and cylinder heads, respectively. In particular vehicle engines and gas turbines are affected by residual silicon. Vehicles with spark ignition engines are developed for fuels, e.g. gasoline, gasoline ethanol blends and natural gas which all are literally free of silicon. The absence of silicon impurities enabled the use of lambda oxygen sensors in front

[8] *Sabine Strauch, Joachim Krassowski, Ankit Singhal*. Biomethane Guide for Decision Makers – Policy guide on biogas injection into the natural gas grid / Fraunhofer UMSICHT WP 2 / D 2.3 April 2013

of the catalyst for exhaust gas control. Deposition of silica on sensor elements impedes oxygen diffusion. High silicon contents misalign oxygen sensors and reduce their durability.

Gas combustion turbines are also vulnerable to silica. By the high velocity of the gas streams hard particles cause erosion or build up deposits. Seizure is reported, when larger chunks of silica break off.

A number of analysis data was collected to estimate the relevance and potential reduction during upgrading of the ***siloxanes*** in biomethane. The highest values were found in the raw gas of sewage sludge digestion in wastewater treatment plants (WWTP) with total siloxanes values of up to 400 mg/Nm3 biogas. Most values ranged between 30 and 60mg/Nm3.

Silicon impurities need to be removed during upgrading of biogas to biomethane. It was shown that after upgrading of biogas from agricultural and food waste, digesters with different technologies siloxanes values dropped as low as 0.3 mg/Nm3.

Recommendations for localization of EU's specifications for biomethane injection in the natural gas network based on the standard EN16723-1.

Initially most of the existing standards for biomethane were developed in European countries. They regulated biomethane properties for injection in NG grid and the use biomethane as a motor fuel is (in Sweden - SS155438:1999). Table 3.6 below illustrates the comparative requirements of national standards for the composition of biomethane in several European countries. It is evident that initially the quality requirements for biomethane varied widely from country to country.

Table 3.6 –Requirements of national standards for the composition of BM[9]

Component	Unit	Austria a)	France	Belgi-um	Czech Republic	Germany	Nether-lands	Sweden	Switzer-land
CH_4	% vol.	≥ 96	≥ 86	≥ 86	≥ 95		≥ 85	≥ 97	≥ 96
CO_2		≤ 3	≤ 2,5	≤ 2,5	≤ 5	≤ 6 (dry)	≤ 6	≤ 3	≤ 6
O_2		≤ 0,5	≤ 0,01		≤ 0,5	≤ 0,5 (wet), 3(dry)	≤ 0,5	≤ 1	≤ 0,5
H_2		≤ 4	≤ 6	≤ 0,1		≤ 5	≤ 12 (0,5)	≤ 0,5	≤ 4
CO			≤ 2	≤ 0,2			< 1		
S total	mg/ nm^3	≤ 10	≤ 30	≤ 30	≤ 30	≤ 30	≤ 45 (16,5)	≤ 23	≤ 30
H_2S (+COS in France and Belgium		≤ 5	≤ 5	≤ 5	≤ 7	≤ 5	≤ 5	≤ 10	≤ 5
Mercaptans		≤ 6	≤ 6	≤ 6	≤ 5	≤ 15	≤ 10 (6)		≤ 5 ppmV
Halons		0	≤ 1 (Cl) ≤ 10 (F)	≤ 1 (Cl) ≤ 10 (F)	≤ 1,5 (F+Cl)	0	≤ 50/25 (Cl/F)		≤ 1
Heavy metals			≤ 1 (µg, Hg)	≤ 1 (µg, Hg)		≤ 5			≤ 5
Siloxanes		≤ 10			≤ 6 (Si)		≤ 5 ppm = 6.2 (Si) (0.08 (Si))		

[9] *Mattias Svensson*. Biomethane standards. Gas quality standardization of biomethane, going from national to international level / European workshop Biomethane, Brussels 11 March 2014

Component	Unit	Austria [a)]	France	Belgium	Czech Republic	Germany	Netherlands	Sweden	Switzerland
Ammonia		Tech. absent	≤ 3	≤ 3	No		≤ 3	≤ 20	≤ 20
H_2O				≤ 110				≤ 32	
Water dew point	°C	≤ -8, 40 bar	≤ -5, P_{max}		≤ -10	Ground tempera-ture	≤ -10, 8 bar (≤ -8, 70 bar)	≤ t_{min}-5	Co conden-sate
Odorant		By demand	15-40 mg THT/m^3			By demand	>10, 18-40 mg THT/m^3		
Particles		Tech. absent	Tech. absent		No particles	No particles	Tech. absent	≤ 1 (μmol)	

Designation: a) - OEVGW G31 / G33;

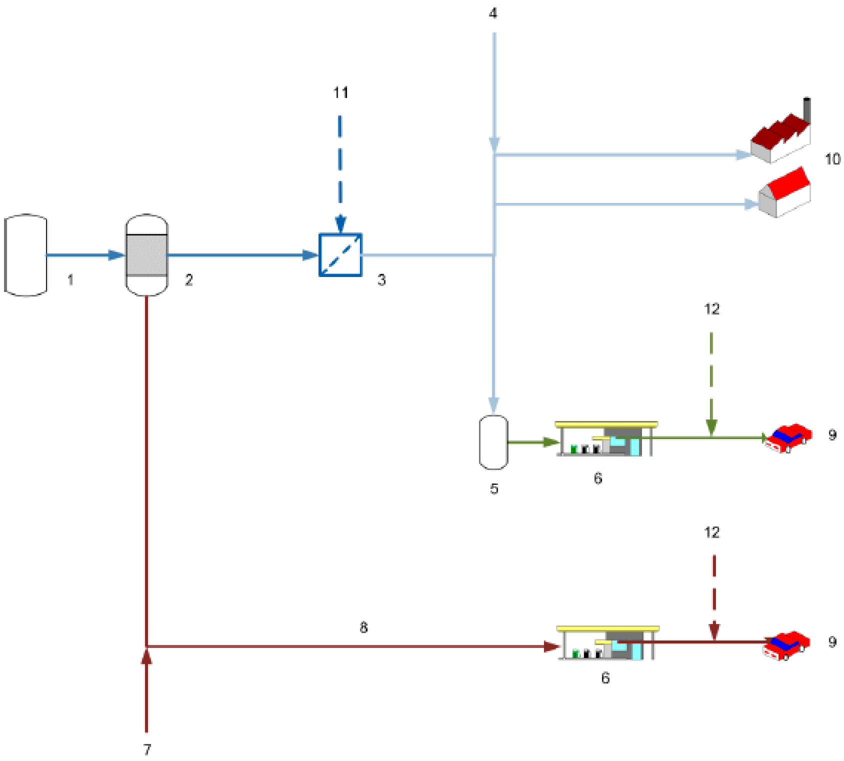
In 2011 CEN[10] was given the mandate to elaborate a set of quality specifications for biomethane to be injected in natural gas pipelines (network) and to be used as a fuel for vehicle engines in one standard. Biomethane in this context can be produced from biological (fermentation, digestion) and thermochemical processing (gasification) of biomass and is appropriate to be used as a blending component to natural gas. This standard was prepared by committee CEN/TC408 according to the European Commission standardization mandate M/475.

It was concluded to formulate one standard but in two parts, Part 1 on biomethane for injection into natural gas grids and Part 2 on biomethane as fuel (including natural gas).

CEN/TC408 released the document FprEN 16723 Part 1 in 2014. The final vote finished in August 2016. In most of the countries the standard has been adopted meanwhile. The standard includes following general parameters:

- Natural gas, biomethane and blends of those intended for injection into natural gas networks shall be free from any constituents or impurities other than the ones described in this standard, to the extent that it cannot be transported, stored or utilized without quality adjustment or treatment. In the case of such other constituents and/or impurities, it may be necessary to obtain an approval from the competent and legitimate authority to define the acceptable risk in the territory of the injection point.
- Health criteria assessment for biomethane is complex and dependent upon the biogas feedstock and upgrading and purification process. As a result, it is recommended that contaminants to be specified and limits to be applied are assessed at national level using an appropriate methodology.
- Biomethane shall meet the requirements of EN 16726 for common parameters.

[10] CEN - *Comité Européen de Normalisation*



1 biogas from digestion or thermos-chemical processes
2 upgrading
3 injection into the gas grid
4 natural gas grid
5 conditioning
6 refueling station
7 non-grid sourced natural gas
8 local dedicated infrastructure
9 automotive use
10 domestic and industrial use
11 Part 1: grid specification
12 Part 2: automotive specification

Fig. 3.1– Representation of some flows and uses of biomethane and nature gas by EN16723-1/2

Table 3.7 contains only parameters specific to biomethane required for injection into H and L gas systems.

Table 3.7 – Parameters specific to biomethane required for injection into H and L gas systems

Parameter	Unit	Limit values		Test method
		min	max	
Total volatile silicon (as Si)	mgSi/m3		0,3 (pure) to 1 (deluted)	EN ISO 16017-1:2000 TDS-GC-MS
Compressor oil		Free from impurities		ISO 8573-2:2007
Dust impurities		Free from impurities		ISO 8573-4:2001
Chlorinated compounds		-	based on health assessment criteria	EN 11911:2010
Fluorinated compounds				NF X43-304:2007 ISO 15713:2006
CO	% mol	-	0,1	EN ISO 6974 series
NH3	Mg/m3		10	NEN 2826:1999 or VDI 3496 Blatt 1:1982-04, NF X43-303:2011
Amine	Mg/m3		10	VDI 2467 Blatt:1991-08

Currently three separate documents are available:

1. EN 16723-1:2016 Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 1: Specifications for biomethane for injection in the natural gas network[11]
2. EN 16723-2:2017 Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 2: Automotive fuels specification[12]
3. EN 16726:2015+A1:2018 Gas infrastructure - Quality of gas - Group H[13]

Their relation in term of parameters limits could be demonstrated by the following table 3.8

Table 3.8 - Demands of the standards EN 16723-1:2016, EN 16723-2:2017, and EN 16726:2015+A1:2018

Parameter	EN 16723-1	EN 16723-2
Silicon conc.	≤ 0.3 to 1 mg/m^3	≤ 0.5 mg/m^3
Hydrogen fraction	by EN 16726	≤ 2 %
Hydrocarbon dew point	by EN 16726	≤ -2 ^{0}C
Oxygen fraction	by EN 16726	≤ 1 %
Sulphur content	≤ 20 mg/m^3	≤ 5 mg/m^3
Methane number	by EN 16726	≥ 65 (80 for high grade)
Compressor oil content	“de deminis”	“de deminis”
Dust impurities	“de deminis”	≤ 10 mg/L
Amines content	≤ 10 mg/m^3	≤ 10 mg/m^3
Water dew point	by EN 16726	≤ -10 ^{0}C
Chloride conc.	“de deminis”	
Fluoride conc.	“de deminis”	
Carbon monoxide fraction	≤ 0.1 %	
Ammonia conc.	≤ 10 mg/m^3	

“de minimis” means an amount that does not render the fuel unacceptance for use in end-used applications

The demands of the EN 16726:2015+A1:2018 are shown in the table 3.9 below

Table 3.9 – Demands of the EN 16726:2015+A1:2018 for gas parameters

Parameter	Units	Limit values for standard conditions 15/15		Limit values for normal conditions 25/0 (for reference)		Test methods [d] (for reference)
		min	max	min	max	
Mercaptan sulfur without odorant (as sulfur)	mg/m^3	not used	6[a]	not used	6[a]	EN ISO 6326-3, EN ISO 19739
Oxygen	mol/ mol	not used	0,001% or 1% (see below)	not used	0,001% or 1% (see below)	EN ISO 6974-3 EN ISO 6974-6, EN ISO 6975
	At the points of entry into the network and connection nodes, the molar fraction of oxygen, expressed as a variable average over 24 hours, should not exceed 0.001%. However, in cases where it is shown that the					

[11] https://standards.iteh.ai/catalog/standards/cen/55154af1-529b-407d-890c-b9e16c935898/en-16723-1-2016

[12] https://standards.iteh.ai/catalog/standards/cen/bb646037-ec22-4cd4-aad4-902ea1b8e0d5/en-16723-2-2017

[13] https://standards.iteh.ai/catalog/standards/cen/2c15cc1a-ff60-4611-b913-842a1ac2926a/en-16726-2015a1-2018

Parameter	Units	Limit values for standard conditions 15/15		Limit values for normal conditions 25/0 (for reference)		Test methods [d] (for reference)
		min	max	min	max	
	gas is not supplied to structures sensitive to higher oxygen content, such as underground storage systems, a higher maximum oxygen content of up to 1% may be applied.					
Carbon dioxide	моль/моль	not used	2,5% або 4% (див. нижче)	not used	2,5% або 4% (див. нижче)	EN ISO 6974 частини 1–6 EN ISO 6975
	At the points of entry into the network and connection nodes, the molar fraction of carbon dioxide should not exceed 2.5%. However, in cases where it is shown that the gas is not supplied to structures sensitive to higher carbon dioxide content, such as underground storage systems, a higher maximum carbon dioxide content of up to 4% may be applied.					
Hydrocarbons dew point [b,c] For any pressure from 0,1 to 7 MPa (70bar) absolute pressure	°C	not used	–2	not used	–2	ISO 23874, ISO/TR 12148
Water dew point [b,c] At 7 MPa (70 bars) or, if less than 7 MPa (70 bars), at max operational gas system pressure	°C	not used	–8	not used	–8	EN ISO 6327, EN ISO 18453, EN ISO 10101 Parts 1–3
Methane number	No units	65	not used	65	not used	See attach. A
Contaminating impurities	The gas shall not contain components, other than those listed in Table 1, in an amount that prevents its transportation, storage and / or use without quality adjustment or processing					
[a] – The figures are given in whole values due to inaccuracies in the calculations. [b] – Under certain climatic conditions, a higher dew point temperature for water and a dew point for hydrocarbons can be adopted at the state level. [c] – More detailed information on the dew point for water and the dew point for hydrocarbons is given in Attachment C. [d] – Methods of determination other than those listed in the standards listed in Table 1 may be used, provided that they are shown to be suitable for this purpose.						

Currently it could be recommended for Ukraine to adopt for internal us the current version of the standards including at least:

1. EN 16723-1:2016 Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 1: Specifications for biomethane for injection in the natural gas network[14]
2. EN 16723-2:2017 Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 2: Automotive fuels specification[15]
3. EN 16726:2015+A1:2018 Gas infrastructure - Quality of gas - Group H[16]

In October 2016 CEN/TC408 initiated a research project to study the missing or insecure values of 16723 parts 1 and 2. The proposal was accepted by the Commission for financing through Horizon

[14] https://standards.iteh.ai/catalog/standards/cen/55154af1-529b-407d-890c-b9e16c935898/en-16723-1-2016

[15] https://standards.iteh.ai/catalog/standards/cen/bb646037-ec22-4cd4-aad4-902ea1b8e0d5/en-16723-2-2017

[16] https://standards.iteh.ai/catalog/standards/cen/2c15cc1a-ff60-4611-b913-842a1ac2926a/en-16726-2015a1-2018

2020 program. Leading sub-contractor is the consortium of AFNOR and GERG[17]. The project bases on the detailed literature search of GERG finished in 2016. The project addresses four independent topics:

- Impact of siloxanes on heavy duty engines;
- Impact of sulphur on catalytic converters and performance of engines;
- Impact of oxygen on underground storages;
- Impact of components on health

The aim of the GERG biomethane project is to gather robust technical information regarding the impacts of biomethane trace components on the gas infrastructures and on the end-users' equipment to propose revision of the standards using strong technical arguments. The first step of the project was literature and operational data review to identify the gaps of knowledge. It focuses on two aspects:

- Impact of the biomethane trace components in terms of corrosion: CO, HCN, H2S, NH3, HCl, HF, organo-halides, micro-organisms;
- Impact of silica compounds (siloxanes) found in biogas sources both on the gas infrastructure (pipes, compressors, valves) and on end-users (boilers, engines).

The extensive review performed highlighted the gaps of knowledge regarding the impact of biomethane trace compounds on gas infrastructure and on gas users. In particular, the study shows that the impact of siloxanes on heavy duty engines and on some boilers needs further understanding, as well as the impact of biomethane on some materials, especially in the presence of water (which is the case in underground gas storage).

This project will help to obtain threshold values in agreement with the interests of all the stakeholders needed to develop a successful biomethane industry in Europe:

- Biomethane producers: need to have limited treatment / upgrading costs to guarantee the economic viability of the projects, and thus the development of the biomethane sector;
- Grid operators: need to protect the grid infrastructure while including renewable gases in the grid;
- End-users: need to protect their equipment (boilers, engines, etc).

When the deliverables are available, CEN/TC 408 will be able to launch a revision of EN 16723-1 and EN 16723-2 to take them into account. The revised standards will allow more biomethane production projects to be economically viable. It will also help develop the use of biomethane by re-assuring manufacturers of equipment about using biomethane and end users.

[17] https://www.gerg.eu/wp-content/uploads/2019/10/Biomethane_Autumn2017.pdf

Economic conditions and technical aspects of biomethane supply to gas networks pipelines

Feasibility study for biomethane production

The economic feasibility of biomethane production in Ukraine needs to be justified, due to the uncertainty of the key factor of influence, namely the guaranteed price and possible fluctuations in the price of biomethane. Based on the projected price of biomethane, the feasibility of biomethane projects will depend on the concept and scale of the project, logistics concepts for raw materials and for commodity and derivative products of technology.

Biomethane project concepts

There are two basic project concepts of biomethane production from biogas. The first concept involves the construction a “greenfield” plant. The second concept envisages the conversion of existing biogas plants from electricity / heat production to biomethane production.

The first concept combines the construction of a new biogas plant and a biogas upgrading plant. A significant advantage of this scheme is the flexibility to choose the construction site, depending on the availability of raw materials and the ability to supply biomethane to the network or its alternative consumption. Thus, the economic model of such an enterprise can take into account in advance the consumption potential of commercial biomethane and the reasonable cost of its production depending on the scale of the project. It is also obvious that such a concept will require significantly more investment in the project, compared to the second concept.

The second concept allows to significantly reduce the amount of new investment costs and may be appropriate in case of economic inexpediency of further production of only electricity / heat. The advantage of this approach is also that the existing facility is more predictable in terms of operating costs, quality and volume of available raw materials, volume and stability of biogas production and its quality. The economic and technical feasibility of such a concept will largely depend on the following factors:

- which revamping measures are necessary to extend the lifetime of the AD unit?
- is it possible to increase the biogas production capacity?
- if yes, which additional investments are needed in the AD unit (e.g., for receiving the additional substrates, adding pretreatment/mixing, pumping capacity, etc.)?
- is the existing biogas desulphurisation solution acceptable for the upgrading unit or new desulphurisation unit must be installed?
- is there sufficient space available for installing the upgrading unit (space limitation may influence the selection of the upgrading technology)?
- which part of the electricity generation equipment (CHP) will remain in operation to supply electricity to both the AD and upgrading units?
- what are the technical conditions for natural gas grid connection on the location (pressure, etc.)?

Both the first and the second project concepts may have some variations, primarily in combining the production of renewable gases using different technologies.

For example, a combine scheme of hydrogen and biomethane production is possible. The carbon dioxide formed as a result of biogas enrichment is combined with hydrogen to form synthetic methane. This approach allows to fully converting carbon from biogas into methane.

Another possibility of combining hydrogen with biogas is its bioconversion, even before the stage of purification of biogas. There are 2 main types of such technologies - in-situ (the process takes place directly in the bioreactor, where biogas is released) and ex-situ (the process occurs when biogas and hydrogen pass through a separate bioreactor). The share of carbon dioxide in biogas decreases, while the share of methane increases.

This study considers the concept of building a new biomethane plant using common technologies of physical and chemical enrichment of biogas to biomethane. The concept of retrofitting of existing production is specific to each individual biogas plant. The concepts of combining the two technologies of hydrogen and biomethane production are not currently widely tested.

Substrate concepts

Raw material logistics is a key factor in determining how successful a biogas and thus biomethane project can be.

The presence of raw materials in an economically feasible delivery radius determines the potential capacity of the biomethane plant. As a rule, biogas plants are built near the source of the basic type of raw material, which can be a separate enterprise (farm, sugar factory, etc.). Preferably, the amount of basic raw material is sufficient only for low or medium capacity biogas / biomethane production projects. The organization of powerful production of biomethane in such cases will require the involvement of other raw materials.

To date, the most common approach in ensuring the production of biogas with sufficient raw materials has been the use of specially grown corn for silage. Anaerobic fermentation of a significant proportion of silage in the mixture fed to the bioreactor is a widely tested technology, and therefore this approach will have minimal technological risks. The main disadvantage of this approach stems from the latest visions and requirements of the European Community on the sustainability of agricultural practices, which provide for the use of land resources primarily to ensure food production. Therefore, the cultivation of energy resources on arable land, including silage corn for biogas, will be considered a unsustainable practice that will affect the ability and / or size of support for biogas / biomethane production through various financial mechanisms.

From the point of view of sustainability of agricultural production, the use of crop residues for biogas production, provided they are returned to the arable land with digestate, is considered an acceptable practice. Therefore, in biomethane production projects focused on its export to EU countries, it is advisable to consider this approach first. Due to the significant share of arable land in Ukraine, crop residues in Ukraine are generated in the vast majority of districts. Potentially, this makes it possible to consider the organization of large-scale production of biomethane in a large part of Ukraine.

Another approach to providing a powerful biomethane plant with raw materials may be the concept of centralized processing of waste and by-products into biogas. This approach assumes that the biogas plant is primarily an enterprise for the disposal and stabilization of various types of waste (eg, waste from various livestock enterprises, food waste from settlements, by-products of the food processing industry, etc.). This approach is widely practiced, for example, in Denmark. However, the implementation of this approach in Ukraine will require the creation of appropriate mechanisms, as well as legal and regulatory framework for cooperation between waste suppliers, biogas plant operator and agricultural land owners, where recycled waste is most likely to be exported. The entrance fee for the processing of certain types of waste can be considered as a prerequisite for the commercial attractiveness of this type of project.

Product concepts

The main types of biogas technology products are:

- crude biogas for direct combustion
- crude biogas as a precursor for the synthesis of methane using hydrogen
- electricity from biogas
- thermal energy from biogas
- crude digestate and its fractions after mechanical separation
- enriched digestate and its derivatives
- commercial biomethane for injection into gas distribution networks
- commercial biomethane for injection into the gas transmission network
- compressed biomethane (CBG)
- liquefied biomethane (LBG)
- food grade carbon dioxide
- carbon dioxide for industrial use (except food industry)
- reduction of greenhouse gas emissions

Until recently, the predominant types of biogas technology products in the world were electricity and, in part, thermal energy, as well as liquid and solid fractions of digestate. With the development of technologies and conceptual visions of the role of biogas technologies, integrated technologies are gaining more and more development, providing maximum use of valuable resources, as well as deeper integration and synergy with energy production, food, waste management, environmental protection, etc.

Today there is no single optimal model for the production and use of biogas technology products. The determining factors are, first of all, the market needs of individual countries or regions in a particular type of product, market prices for individual products of technology, as well as existing financial incentive schemes.

Biomethane production from biogas was developed based on the idea of maximizing the use of biogas energy, and thus more economical use of biomass resources, since in the vast majority of cases the efficiency of biogas energy utilization in cogeneration technologies was only 35-40%.

Given the wide range of uses of natural gas and the affinity of biomethane with the latter, there are more alternatives to the useful utilization of biogas energy. At the same time, the most viable concept will obviously be the one in which the output can get the most benefit from the implementation of all possible types of biogas technology products.

In this study, the financial analysis is performed for the concept of production of commercial biomethane for injection into low/medium pressure gas distribution networks (up to 6-12 bar). The economic effect of the use of digestion fractions after separation is considered. Production of marketable carbon dioxide or other products was not considered.

Feasibility study for 500 m^3CH_4/hour biomethane plant construction

This feasibility study uses the initial data, assumptions and calculations developed by the REGATRACE working group, a member of which is the Bioenergy Association of Ukraine. The model used takes into account the peculiarities of the local market, in particular energy tariffs, project support schemes.

Raw materials. Biogas production forecast

The project model is designed for the predominant consumption of raw materials and by-products of agricultural origin, including chicken manure and pig manure, corn stalks, corn silage, catch crops. Additionally, the use of biowaste is also provided - 6% of the input mass of the mixture. At the same time, 7.1% of methane is expected from biowaste, 29.5% - from corn silage. The use of crop residues is expected at the level of 12% by input mass, which will result in almost 16% of methane from total production (Table 4.1).

Table 4.1 – Raw materials used and biogas production forecast

Raw material type	Volume	DM	oDM	Biogas	Biogas	CH_4	CH_4	Share
	ton/year	%	%	Nm^3/ton oDM	Nm^3/year	%	Nm^3/year	%
Cattle slurry	30 000	8	85	350	714 000	55%	392 700	7,68
Poultry manure	15 000	30	75	500	1 687 500	55%	928 125	18,15
Biowaste	5 000	30	85	550	701 250	52%	364 650	7,13
Maize stover	7 000	65	82	580	2 163 980	51%	1 103 630	21,58
Catch crops	10 000	27	92	620	1 540 080	53%	816 242	15,96
Maize/ sorghum silage	15 000	32	93	650	2 901 600	52%	1 508 832	29,50
Recirculation	20 000	5	30,5	0	0	0%	0	0
Total/average	102 000	21			9 708 410	52,7%	5 114 179	100

About 30% of the liquid fraction of the digestate is planned to be sent for mixing with the feedstock to balance the water content in the bioreactor. The total expected methane production is 5,114,179 m^3CH_4/year.

The cost of raw materials, as shown in Table 4.2, is taken into account the current market prices in Ukraine and the cost of delivery with an average radius of 25 km (vegetable raw materials), 15 km (manure, biowaste). The total cost of raw materials will be 1,330,000 euros, and the average raw material component of the cost of production of 1 m^3CH_4 will be 0.26 EUR/m^3CH_4. Comparison of the specific raw material cost of methane production from traditional corn silage and from corn crop residues or cover crops, shows a significant advantage of the latter, with a ratio of 2 times or more.

Table 4.2 – Raw materials cost

Substrate	Substrate cost			
	UAH/t	EUR/t	EUR/m^3 CH_4	EUR/year
Cattle slurry	60	2	0.012	60 000
Poultry manure	450	15	0.044	225 000
Biowaste	450	15	0.015	75 000
Maize stover	900	30	0.041	210 000
Catch crops	840	28	0.055	280 000
Maize/sorghum silage	960	32	0.094	480 000
Total/average			0.260	1 330 000

Biomethane plant configuration

This model of biomethane production envisages a new construction of a biogas plant and a biogas upgrading plant. The considered technological solutions consist of the following key elements.

Biogas plant

In view of the assumed composition of substrates in the model the pre-treatment is limited to sizing: one cutting equipment is needed for bringing the cattle manure (with straw) and the substrates of vegetation origin down to particle size of max 40 mm.

The model envisages construction of wet type fermenters with a conservative organic load rate of 2.8 kg oDM/m^3 digester volume/day. The average HRT was estimated as 60.8 days (Table 4.3). The specific biogas production of 1.56 Nm^3/m^3 digester volume indicates that at 17,000 m^3 digester volume the fermentation system will have reserve capacity.

Table 4.3 - Digester volume estimation

Parameter	Dimension	Value
Organic dry matter (oDM) input	to/year	17 369
Average organic dry matter (oDM) input	kg/day	47 586
Organic load (average)	kg oDM/day/m^3	2.8
Digester volume recommended based on organic load	m^3	13 596
Input volume	m^3/day	279
Average hydraulic retention time (HRT)	days	60.83
Digester volume based on HRT	m^3	17 000
Specific biogas production	m^3/m^3/day	1.56

Biogas upgrading plant

No upgrading technology was identified, and no substantial thermal energy consumption was assumed. The value 0.33 kWh/Nm^3 of biogas electricity consumption was considered. Heat consumption by an upgrading plant assumed to be zero.

Energy supply

Both the anaerobic digestion and upgrading units consume electrical and thermal (only for some upgrading technologies) energy. Unlike a conventional biogas CHP plant concept, there are few possible energy supply schemes in biomethane production concept. The principal decision to be taken at early stage is the following: should the energy consumption of the installation be covered fully or mainly from own sources or – on the contrary – importing electricity and source(s) of thermal energy is preferred.

To a large extent, this will depend on the future cost of electricity and heat produced at CHP from biogas. Possible power supply schemes can be, for example:

A. Local CHP for self-supply of energy
B. External energy supply through importing electricity and natural gas from the respective grids.
C. External electricity supply, local biogas boiler for heating the digesters.

The straightforward solution for energy self-supply is to install a CHP (combined heat and power) unit burning biogas, generating electricity, and producing heat in form of hot water.

Pros for indigenous energy supply:

- the full volume of produced biomethane is qualified as renewable methane (while no fossil energy was consumed in the production processes),
- the regulations of applicable national financial support schemes may prohibit the consumption of fossil energy sources (this is not regulated in Ukraine by now),
- self-supply protects from potential disruption of supplies from external sources,
- self-supply protects from potential future price increases for external sources (electricity, natural gas) and provides a stable basis for the cost projection of energy supply.

Cons for indigenous energy supply:

- electricity and thermal energy produced by the local CHP may be more expensive than the imports from external sources – this is very much dependent on the price mechanisms valid on the domestic energy markets,
- for the security of operations, the connection to the electricity grid (as a back-up) is needed in any case.
- maintaining the process temperature in the digesters at times when the CHP is not in operation may require access to outside thermal energy source anyway.

Full independence from external energy sources cannot and should not be aimed at: the most sensitive part of the machinery and equipment must be operated, the process temperature in the digesters should be maintained also at times of disruption of the local CHP operation (for example for maintenance, etc,).

The easiest way of securing a back-up electricity supply is to establish a connection to the electricity grid with entitlement to take electricity any time. Alternatively, a local electricity generator could be installed, which would operate only in case of emergency.

The security of thermal energy supplies can be achieved in several ways:

- adding a boiler burning biogas to the machinery,
- connecting to the natural gas grid and burning natural gas in a boiler,
- installing a boiler operated with solid biomass (air quality issues/storage of materials might arise).

In this model the installation of one local CHP unit of 500 kW_e capacity is foreseen taking into account the estimated yearly consumption of electricity in the AD and upgrading units. The co-generated thermal energy (usually available in form of hot water) can be used to cover the heat requirements of the digesters. The energy balances is shown in the tables 4.4–4.5.

Table 4.4 – Electricity balance

Parameter	Value, kWh/year	%
Gross electricity production	4 000 000	100.00
AD unit consumption	1 353 000	33.83
Upgrading unit consumption	2 567 179	64.18
Loss of electricity (trafo), %	40 000	1.00
Net electricity production	39 821	1.00

Table 4.5 – Thermal energy balance

Parameter	Value, kWh/year	%
Thermal energy production	4 320 000	100.0%
AD unit own consumption	2 050 000	47.5%
Losses (5%)	216 000	5.0%
Thermal energy sold	1 100 000	25.5%
Thermal energy not utilised	954 000	

The main indicators of the biomethane plant

Gross biogas production amounts to 9.7 mln m^3/yr. Biogas consumption at CHP is 19.4%. Thus, gross methane production (after biogas upgrading) amounts to 512 m^3CH_4/hour, or 4.098 mln m^3CH_4/yr at 8000 full load operational hours.

Gross production of raw digestate estimated at 89 932 t/yr (Table 4.6). After separation 65 505 m^3/year of liquid fraction and 24 427 t/year of solid fraction obtain. As 20 000 m^3 of liquid fraction of digestate is being recycled to anaerobic process 45 505 m^3/year of liquid fraction to be removed (transported for utilisation).

Table 4.6 – Digestate volumes estimations

Parameter	Dimension	Value
Total volume	t/year	89 932
Assumed density	t/m^3	1.0

Parameter	Dimension	Value
DM	%	10.43
Liquid fraction DM	%	5.0
Liquid fraction volume	m^3/year	65 505
Solid fraction DM	%	25.0
Solid fraction weight	t/year	24 427

CAPEX

The estimated investment in this project is € 8,715,000, including € 6,035,000 for the biogas plant and € 2,680,000 for the biogas upgrading plant (Table 4.7).

Table 4.7 – Estimated investment budget

Item	AD	Upgrading	Total
Construction	2 365 000	550 000	2 915 000
Machinery for technology	1 950 000	1 530 000	3 480 000
CHP unit	450 000		450 000
Pipelines	195 000	80 000	285 000
Measuring and steering system	275 000	200 000	475 000
Electricity network connection	80 000	50 000	130 000
Loading machine	150 000		150 000
Roads, fencing	150 000		150 000
Engineering, inspections	170 000	120 000	290 000
Land	100 000		100 000
Other (deliveries, insurance, customs, reserve)	150 000	150 000	300 000
Total	**6 035 000**	**2 680 000**	**8 725 000**

The costs of establishing the grid connection vary in a very broad range. The pipeline cost is a function of the distance between the plant and the gas network, the amount of biomethane produced and the complexity of the civil work requested (i.e., burial, crossing of rivers, motorways, railroads etc.). Assumption has done that natural gas network will be at distance 1 km and gas pipe could be laid down without any infrastructure barrier. In this case pipe construction and connection it to gas network will cost 10 000 euro.

In case the costs of constructing the pipeline connection and the grid injection station are prohibitive, the option of liquification or the delivery in compressed state could be considered. Transportation via compressed composite trailer unit is a competitive alternative for transporting biomethane to central grid injection facility or to directly to off grid gas consumers.

Auxiliary investments will be needed in the period covered by the feasibility studies (i.e. 15 years). While calculating the auxiliary investments, in the model it was assumed that proper, professional maintenance will be consequently provided throughout the operation, what limits the need for replacing parts of machinery.

In the model the auxiliary investments (expressed in percentage of original investment value) were assumed as shown in the Table 4.8.

Table 4.8 - Auxiliary investments

CHP unit year 8	% of original investment	35
Technological machinery years 6-8	% of original investment	20
Technological machinery years 12-15	% of original investment	30
Measuring & steering equipment year 5	% of original investment	25
Measuring & steering equipment year 10	% of original investment	25

In the model the auxiliary investments are not spread evenly among all the years, correspondingly the amount estimated for these financial expenditures is fluctuating year by year. It is assumed that the auxiliary investments will be financed from the operating income, thus reducing the cash flow.

In the model the depreciation (Annex 4-1) calculated with

- 20 years for constructions, pipelines, road,
- 8 years for the CHP, technological machinery,
- 12 years for electricity network connection,
- 5 years for measuring/steering equipment, engineering, etc.

Financing

In the model the financing was calculated under the following conditions, as shown in the Table 4.9. Repayment period in the model proposed 10 years (excluding the grace period) and grace period 18 months.

Table 4.9 – Financing scheme

Item	Value	Dimension
Total investment cost	8 725 000	EUR
Own funds	2 181 250	EUR
Non-repayable investment subsidy	0	EUR
Credit amount capital	6 543 750	EUR
Interest rate	6	%/year
Interest 6 months 2021	196 313	EUR
Interest 12 months 2022	392 625	EUR
Total credit incl. accrued interest	7 132 688	EUR
Credit service	969 104	EUR

OPEX

The estimated operational expenditures amounts to 1 793 330 EUR per year (Table 4.10). The biggest share of this amount relates to raw materials – almost 75% to total value.

Table 4.10 – Estimated operational expenditures

OPEX item	Value	Dimension
Raw materials	1 330 000	EUR/year
Maintenance machinery	169 250	EUR/year
Maintenance constructions	14 575	EUR/year
Spare parts	20 000	EUR/year
Chemicals	10 000	EUR/year
Energy (electricity)	0	EUR/year
Fermentation residue transportation	91 010	EUR/year
Biotechnological service	12 000	EUR/year
Personnel	60 000	EUR/year
Administration, overhead	36 000	EUR/year
Insurance, banking	50 495	EUR/year
Total	**1 793 330**	**EUR/year**

Personnel costs estimated with personnel costs in the magnitude of 5 persons, the yearly labour costs were estimated at 12 000 EUR/full time staff, which means 60 000 EUR/year for the biomethane plant.

The other maintenance costs in the model (Table 4.11) were calculated based on the investment value as follows:

- maintenance of AD machinery: 2,5% of the invested value,
- maintenance of the biogas upgrading machinery: 5,0% of the invested value,
- constructions (digesters, roads, pipelines, etc.): 0,5% of the investment value.

In the first year of operation the maintenance was assumed at 25% level compared to the following years (to consider that the costs are lower in the guarantee period).

Table 4.11 – Maintenance cost projection

Item	Specific value	Dimension	Value	Dimension
CHP maintenance	0.011	EUR/kWh	44 000	EUR/year
Maintenance AD machinery	2.5%	on investment	48 750	EUR/year
Maintenance upgrading machinery	5.0%	on investment	76 500	EUR/year
Spare parts (incl. wear and tear)	20.000	EUR/year	20 000	EUR/year
Maintenance AD constructions	0.5%	on investment	11 825	EUR/year
Maintenance upgrading constructions	0.5%	on investment	2 750	EUR/year
Maintenance total			**203 825**	**EUR/year**

The liquid fraction of the fermentation residue should be applied preferably on the cultivated fields surrounding the location of the biogas plant. It was assumed that the transportation cost for the liquid fraction will be at 2 EUR/m^3.

Revenues

The model envisage revenues from the following sources:

1. Biomethane sales
2. Sales of solid fraction of digestate
3. Sales of a part of heat from CHP

The revenues of the biomethane producer related to the sale of the primary product (biomethane) may consist of several components:

- sales price of the molecules (corresponding to the prevailing prices on the market segment where the physical product is being delivered),
- feed-in-premium (FIP) from a financial support scheme of the national government, if any,
- price premium paid voluntarily by the customer in respect of the „green" value (environment friendly, renewable, sustainable, etc.) of the product, if any,
- price premium paid by the customer in respect of the tax benefits the consumer is granted for purchasing renewable gas,
- income from the sale of Guarantees of Origin, if any,
- income from the sale of biofuel certificates, if any,
- income from the sale of ETS certificates, if any.

For the conditions of Ukraine at present there are no clearly defined schemes by which it is possible and expedient to sell the produced biomethane. Today in Ukraine there is no precedent for the sale of biomethane, as well as its actual production. At the same time, there are examples of direct sales of pre-purified biogas (desulfurized and dried) to enterprises that consume natural gas in production cycles. Mostly, biogas is supplied for the production needs of sugar factories, near which biogas stations are built (biogas plant of Astarta company in Globyne city, biogas plant of Yuzefo-Mykolayivka in Vinnytsia region). Thus, the direct physical sale of energy (molecules) of biogas in Ukraine already takes place and is due to economic feasibility, as at current prices for natural gas (more than 1000 euros/1000 m^3) biogas is competitive.

However, the fluctuation of natural gas prices is a major factor in the uncertainty in developing a financial plan for such projects. For example, in the 2020 season, when the price of natural gas for enterprises barely reached 300 euros/1000 m^3, such an economic model was not viable. The possible price of biomethane will also largely depend on market prices for natural gas, and in this context, long-term planning of financial activities for the project should take into account the risks of a sharp decline in NG prices.

There are 2 main models of sales of commercial biomethane as a substitute for natural gas (models of consumption of biomethane as a motor fuel are not considered here), namely:

1. Sales on the domestic market of Ukraine under direct agreements with enterprises.
2. Implementation of guarantees of origin (virtual export) on the EU market.

Both models can be viable under high natural gas prices - 800-1000 euros/1000 m^3 and more. Additional opportunities may arise with the introduction of the carbon border adjustment mechanism (CBAM), under which it may be appropriate for exporters to EU covered by this mechanism to buy energy from renewable energy sources. Implementation of the mechanism is expected only from 2024. There are no other mechanisms for financial incentives or subsidies for biomethane producers in Ukraine.

The most likely scenario, at the time of preparation of this feasibility study, is trade in guarantees of origin (GoOs) with European traders directly or through a system of virtual exports based on guarantees of origin. This will allow a mutual offset of the physical and virtual volume of biomethane. It is assumed that the physical molecules of biomethane will enter the gas distribution networks of the Ukrainian gas transmission system, and the equivalent physical volume of natural gas in transit will be pumped to the conditional sampling point in the recipient country.

The price for biomethane, which will be sold under this scheme, will most likely be formed according to the formula:

Biomethane price = Stock price for NG + Premium

Current exchange prices for natural gas on the EU market range from 66-99 euros/MWh (equivalent to approximately 660-990 euros/1000 m^3 of biomethane) (Fig. 4.1), although in the last 6 weeks they reached 117 euros/MWh and above.

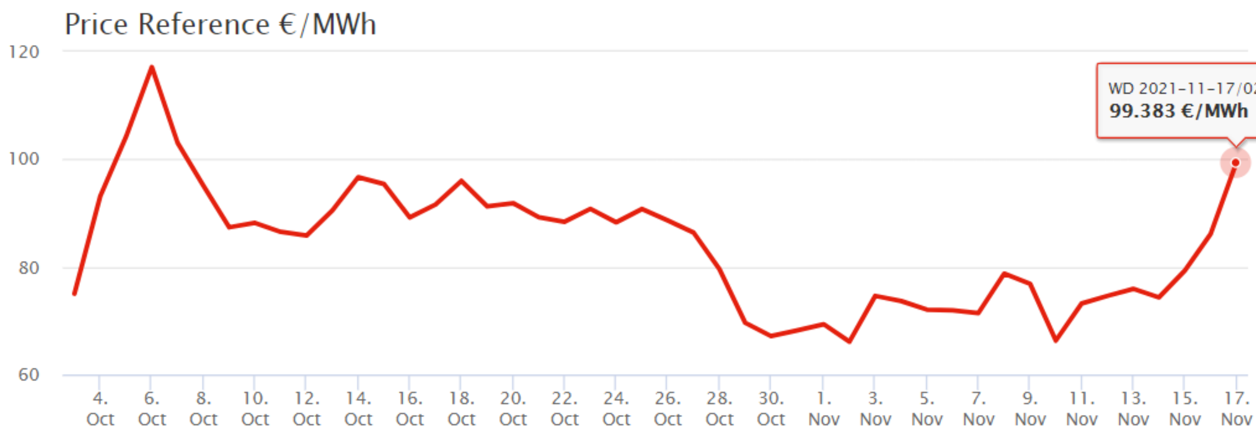


Fig. 4.1 – Reference price for natural gas [[1]]

The premium for guaranteeing the origin of biomethane is announced by potential biomethane traders from Ukraine at the level of 300-400 euros per 1000 m^3 of biomethane. Therefore, the total tariff for biomethane in the current market conditions would be at least 950 euros/1000 m^3. It is difficult to forecast changes in natural gas prices even in the medium term due to a number of non-market factors. However, with the implementation of the Green Deal framework agreement in the EU, one should probably not expect the same low level of natural gas prices, which was, for example, in 2020, at 200-300 euros per 1000 m^3. With a natural gas price of 200 euros/1000 m^3 and a low premium, the tariff for biomethane may be only 500 euros/1000 m^3, which may be insufficient to implement a viable biomethane project.

Given the risks associated with reducing or stopping the transit of natural gas to Ukraine from Russia, the scenario of virtual exports might not be viable. An alternative in this case may be the physical export of biomethane, most likely in the form of liquefied gas.

The considered financial model of the project takes into account the tariff for biomethane 750 euros/1000 m^3, which may be relevant at a price of natural gas 350 euros/1000 m^3 and a higher premium.

[1] https://www.powernext.com/spot-market-data

The financial model takes into account the receipt of income only from the sale of the solid fraction of the digestate. The expected selling price of the digestate is 5.3 euros/ton at a humidity of 75%. This price takes into account market prices for NPK (average 535 euros per 1 ton of active substance), their content in the digestate (a total of 405.5 tons per year), as well as a discount of 40% for non-standard quality compared to mineral fertilizers.

In the model the cash flow calculations were performed under the assumption that part of the biogas is burned in a local CHP unit to secure electrical and thermal energies for the operation from renewable source. Is was also assumed that part of the thermal energy not used for heating the digestate can be utilised in cold months for heating buildings. The value of so utilised thermal energy in included in the revenues of the plant at 0.05 EUR/kWh, what corresponds to heat tariff 1727 UAH/Gcal.

Total estimated revenue amounts to 3 218 223 EUR/yr. Table 4.12 shows the composition of revenues assumed in the model (at full capacity).

Table 4.12 – Composition of revenues in the model

Income source	EUR/year	%	Price	Dimension
Biomethane sales revenue	3 033 623	94,26	0,075	EUR/kWh
Thermal energy local utilisation	54 450	1,69	0,0495	EUR/kWh
Digestate solid fraction	130 149	4,04	5,3	EUR/t
Total income	**3 218 223**	**100,00**		

Cash flow analysis

The resulted IRR of the project at assumed above parameters is 21.48% what could be feasible for investors. NPV (12 years) of the project evaluated at 851 376 EUR. Average ROE for the first 12 years is 14.51%. Cumulated cash flow over 12 years could reach at about 5 mln euros. Cashflow analysis for the period of 16 years shown in the Annex 4-2.

Without heat sales IRR will be 17.94% (NPV over 12 years – 569 375 EUR). Without heat sales and digestate sales IRR decreases to 8.35%.

Thus, with biomethane tariff 750 EUR/1000 m^3, such project could be viable and attractive one if at least solid fraction of digestate to be sold at fertilizer market comparable prices. If project will rely only on biomethane sales its price should be at least 800 EUR/1000 m^3.

Cost and technical requirements for connection to high-pressure and medium/low gas pipelines

The cost of connecting the biomethane producer to the gas network, starting from the point of exit from the metering and quality control unit of biomethane, which is located directly at the biomethane plant and is part of it, may consist of the cost of laying the pipeline and the cost of compressor station.

The cost of laying a gas pipeline, as mentioned above, can vary widely, depending on the presence of natural or engineering (infrastructure) obstacles on the line of its possible laying. Therefore, such an assessment can only be made for a specific case.

According to DBN B.2.5-20: 2018 "Gas supply"[2] gas pipelines depending on the pressure of the gas transported by them are divided into the following categories:

- high pressure gas pipelines of the first category - at working pressure of 0.6-1.2 MPa (6-12 bar)
- high pressure gas pipelines of the second category - at working pressure of 0.3-0.6 MPa (3-6 bar)
- medium pressure gas pipelines - at working pressure of 0.005-0.3 MPa (0.05-3 bar)
- low pressure gas pipelines - at working pressure up to 0.005 MPa

This DBN regulates the design standards for gas supply systems with pressures up to 1.2 MPa, in fact, distribution gas networks. Thus, all gas networks with a pressure above 1.2 MPa, belong to the gas transmission networks, where the pressure is from 12 to 60 bar. A priori such networks are of high pressure.

For example, the estimated cost of laying and connection to the high pressure gas network of category 2 (up to 6 bar) underground gas pipeline made of polyethylene pipe PE100 SDR17.6 with a nominal diameter of 65-110 mm may be 10-15 thousand euros, respectively.

Table 4.13 shows an example of estimating the cost of laying 450 meters gas pipeline with a diameter of 75x4.3 mm to connect a potential producer of biomethane (biogas plant in the village of Zhuravka) to a high-pressure gas pipeline of the 2nd category with a diameter of 100 mm.

Table 4.13 – Cost breakdown for construction 450 meters of PE gas pipe

Cost item	**Cost estimation**	
	UAH	EUR
Total, incl.:	**128 507**	**4 270**
Earthworks	11 276	375
Construction works	43 963	1 461
The cost of materials, products, structures	63 063	2 095
Assembly and installation of the gas crane unit	4 390	146
Arrangement of the gas carpet	4 656	155
Installation of landmarks	915	30
Insulation	244	8

In this example, there are no natural or other obstacles in the way of laying a pipeline of this length, the terrain is flat, so the cost is close to the lowest possible. The main cost items are the costs of the polyethylene pipeline and its laying in the trench – about 50%. Per 1 kilometer of the route it is 9.5 thousand euros. The estimated flow rate of biomethane for this example is 220 m^3/h.

A polyethylene pipe with a diameter of 110 mm will be sufficient to supply biomethane to the high-pressure distribution network of the 2nd category with an average absolute pressure of 6 bar and a flow rate of 1000 m^3/h.

The need to install a compressor station for the supply of biomethane to the network will be determined on the one hand by the pressure in the network, and on the other - the pressure of the biomethane at the outlet of the metering and quality control unit.

[2] https://dreamdim.ua/wp-content/uploads/2019/04/DBN-V2520-18_Gas.pdf

In most systems using physical and chemical methods of enrichment of biogas at the outlet provides a biomethane pressure of 1.3 to 10 bar, as shown in table 4.14.

Table 4.14 – Operation and outlet pressure by different biogas upgrading technologies [3]

Type of biogas upgrading technology	Operation pressure (bar)	Pressure at outlet (bar)
Cryogenic	80	8–10
Sabatier process	8–10	
PSA	3–10	4–5
Water scrubbing	4–10	7–10
Physical scrubbing	4–8	1.3–7.5
Chemical absorption	Atmospheric	4–5
Membrane separation	5–8	4-6

Given the significant probability of biomethane supply to high-pressure gas distribution networks from 3 to 6 bar, it can be assumed that the connection of the biomethane plant at a short distance from the gas network will not require the installation of an additional booster station.If the mains pressure is higher than the biomethane outlet pressure, a booster compressor station will be required. The cost of the station depends mainly on the generated pressure and gas consumption, the manufacturer. Analysis of available information on the level of prices for gas compressor stations with the possibility of pumping biomethane into high-pressure gas distribution networks up to 12 bar shows that prices average 5-10 thousand euros (Table 4.15).

Table 4.15 – Low-pressure gas compressors characteristics

Type of compressor	Gas flow	Outlet pressure	Electric capacity	Price
	m^3/hour	bar	kW	EUR
Stationary diesel fueled compressor NV-10/8M2	660	7	74	8 667
Compressor NV-10E (electric)	660	7	74	7 333
Screw compressor Atlas Copco GA15	160	7,5	15	3 740
Screw compressor CompAir RA-101	520	10	55	4 700
Compressor ZW-2.4 / 3-6	144	6	18,5	5 000
Compressor MW-19.2/(1∼17) - (17∼25)	1152	17-25	400	10 600

Prices for medium and high pressure compressors were shown in Chapter /// and also presented in Table 4.16.

[3] https://backend.orbit.dtu.dk/ws/files/190081841/BiogasUpgrade_Review.pdf

Table 4.16 – Medium-to-high pressure gas compressors characteristics

Parameter	Value	Option 1	Option 2	Option 3
		Injection to trunk transmission pipelines and/or reverse-pressurizing concept branches trunk pipelines	**Injections to trunk pipeline branches/GRS**	**Injection to end-line (impasse) of branches/GRS**
Annual biomethane flow rate	mln $_Nm^3$/year	50	10	10
Hourly flow rate	$_Nm^3$/hour;	6000	1200	1200
Inlet pressure	bar	1…3	1..3	1..3
Outlet pressure	bar	60…65	40…45	20…25
Cost	mln EUR	**2.5...3**	**0.5…1.5**	**0.25…0.8**

The cost for connection to low-to-medium pressure gas most probably would include only pipeline laying, as describe in the previous chapter.

List of potential biomethane buyers within Ukraine and outside of the country

The list of potential biomethane buyers outside of Ukraine, who already expresses the interest in bying, presented in the Table 4.17.

Table 4.17 – The list of potential biomethane buyers outside of Ukraine

Company	Country	Contact person	Contact information
RWE Supply& Trading GmbH/CZ	Chech Republic	Petr Kalina	+420735156646 Petr.Kalina@rwe.com
Vitol	UK	John Scott Kerr	Nova South, 4th Floor 160 Victoria Street, London SW1E 5LB UK T:+44 (0) 207 973 4201 E: jsk@Vitol.com
AFS Energy	The Netherlands	Kostiantyn Kulyk	+31 (0) 20 5707208 k.kulyk@afsgroup.nl www.afsenergy.nl AFS Energy Beursplein 5 1012 JW Amsterdam The Netherlands

Potential biomethane (biogas) buyers in Ukraine could be the biggest natural gas consumers given the higher prices for NG than for biomethane. Potential buyers of biomethane in Ukraine may be companies with significant consumption of natural gas, given the higher prices for natural gas, compared to biomethane. However, there may be the potential groups of enterprises interested in renewable energy sources like biomethane to fully or partly overcome the CBAM limitations.

The CBAM mechanism will on the first stage cover the part of industrial sectors, namely: iron and steel, refineries, cement, organic basic chemicals, and fertilizers[4]. The companies in respective sectors in Ukraine may potentially be covered by CBAM and may have a necessity to reduce carbon intensity via, among others, substitution of fossil fuel in production cycle by biomethane utilization. The list of respective companies which are potential biomethane buyers within Ukraine and at the same time candidates for connection of biomethane plants are presented in Table 4.18.

Table 4.18 – The list of potential biomethane buyers in Ukraine

ID #	Company name	Location of production premises	Region	Estimated NG consumption scale, million nm^3/year
Cement and concrete industries				
1	MykolaivCement	49°31'03.9"N 23°56'55.3"E	L'viv	50
2	Ivano Frankivsk cement	48°58'30.5"N 24°42'47.8"E	Ivano Frankivs'k	50
3	Kamyanets-Podilsky cement	48°44'57.2"N 26°36'20.4"E	Khmel'nyts'k	70
4	Volyn cement	50°32'48.8"N 26°15'38.2"E	Rivne	40
5	Balakliya cement	49°29'39.0"N 36°44'50.4"E	Kharkiv	70
6	Kryvyi Rih cement	47°52'19.9"N 33°26'20.0"E	Dnipropetrovsk	50
7	Odesa cement	46°30'26.4"N 30°40'27.2"E	Odesa	35
8	Yugcement (Olshansky cement)	47°10'16.7"N 31°45'32.2"E	Mykolaiv	50
9	Donetsk cement (Amvrosiivka)	47°48'06.5"N 38°27'56.0"E	Donetsk	40
10	Dnipro cement	Dnipro city, Kamjanske city	Dnipro	35
11	Kramatorsk cement	48°43'46.7"N 37°32'38.9"E	Donetsk	35
12	Vatutino firebrick combinate	49°01'03.7"N 31°01'09.7"E	Cherkasy	15
	TOTAL			**540**
Chemical and petrochemical industries, fertilizers production				
13	OSTCHEM Rivneazot	50°42'38.5"N 26°09'48.2"E	Rivne	250
14	OSTCHEM Cherkasyazot	49°22'27.0"N 32°03'49.1"E	Cherkasy	400
15	OSTCHEM Severodonetsk	48°56'28.2"N 38°27'54.8"E	Luhansk	350
16	Alchevsk coke chemical plant	48°28'12.6"N 38°45'47.1"E	Luhansk	150
17	Avdiivka coke chemical plant	48°10'10.5"N 37°42'08.9"E	Donetsk	100
18	Odesa port plant	46°36'58.9"N 31°00'30.3"E	Odesa	250
19	Dniproazot (Kamjanske)	48°29'16.8"N 34°40'03.9"E	Dnipro	250
	TOTAL			**1750**
Iron, Steel, aluminum and ferrous production				
20	Krymskyi Titan	46°12'11.0"N 33°39'42.4"E	Kherson	100
21	Nikopol ferroalloy plant	47°37'56.6"N 34°20'55.9"E	Dnipro	100
22	Mykolaiv aluminium	46°46'14.0"N 31°57'11.3"E	Mykolaiv	350
23	Arcelor mittal Kryvyi Rih	47°52'21.2"N 33°22'39.6"E	Dnipro	300

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021PC0564&from=en, Article 30

ID #	Company name	Location of production premises	Region	Estimated NG consumption scale, million nm³/year
24	Sev-GZK Kryvyi Rih	48°10'03.5"N 33°32'57.1"E	Dnipro	150
25	Yuzhny GZK Kryvyi Rih	47°49'20.5"N 33°20'27.8"E	Dnipro	100
26	Central GZK Kryvyi RIh	48°04'21.6"N 33°23'03.6"E	Dnipro	110
27	Poltava GZK	48°59'54.4"N 33°40'11.0"E	Poltava	180
28	Dnipro steel plant named after Petrovsky	48°28'51.3"N 34°58'33.7"E	Dnipro	130
29	DMK (Kamjanske)	48°31'18.1"N 34°37'43.2"E	Dnipro	200
30	Dnipro coke chemical plant	48°28'20.4"N 34°58'03.9"E	Dnipro	80
31	Interpipe Dnipro	48°29'28.5"N 35°05'13.9"E	Dnipro	150
32	Zaporizhstal	47°51'51.5"N 35°09'24.5"E	Zaporizhzhya	200
33	Zaporizhzhya ferroalloy plant	47°52'01.8"N 35°08'09.1"E	Zaporizhzhya	100
34	Zaporizhzha coke chemical plant	47°51'45.7"N 35°08'39.5"E	Zaporizhzhya	100
35	Dniprospetzstahl Zaporizhzhya	47°51'35.1"N 35°09'34.9"E	Zaporizhzhya	50
36	Azovstal Mariupol	47°06'13.8"N 37°36'12.3"E	Donetsk	150
37	MMK named after “Illitsch”, Mariupol	47°09'19.7"N 37°33'49.6"E	Donetsk	150
38	KZMO complex (Kostiantynivka)	48°31'07.6"N 37°42'22.0"E	Donetsk	130
39	Bakhmut ferrous plant	48°36'44.1"N 37°59'36.4"E	Donetsk	70
40	Energomashspetzstahl Kramatorsk	48°46'30.2"N 37°34'44.6"E	Donetsk	100
	TOTAL			**3000**

Depending on sector, individual consumption of natural gas of presented companies currently is estimated as 45-250 million nm³/year. This consumption scale allows to connect or cover several biomethane plants at once. Most consumption (80%) is geographically situated in Dnipro, Donetsk, Zaporizhzhya, Cherkasy regions.

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Legal analysis of the terms and requirements of the Ukrainian legislation governing injection of biomethane into the gas distribution or gas transmission system, and its further transmission as a commodity from Ukraine to the EU

I. DEFINITIONS

Client shall mean potential producer of biomethane planning to connect the biomethane production facility to the gas distribution and gas transmission systems, to inject biomethane to such systems and gas storage facilities, and transmit it to the EU.

Gas Law shall mean Law of Ukraine On the Natural Gas Market No. 329-VIII, dated 09.04.2015.

Regulator shall mean the National Commission for State Regulation of Energy and Public Utilities.

GTS shall mean the Gas Transmission System of Ukraine.

GDN shall mean the Gas Distribution Networks.

Gas Storage Facilities or Underground Gas Storage Facilities (UGSF) shall mean underground gas storage facilities.

GTS Code shall mean the Code of Gas Transmission System approved by Order of the Regulator No. 2493, dated 30.09.2015.

GDN Code shall mean the Code of Gas Distribution System approved by Order of the Regulator No. 2494, dated 30.09.2015.

Gas Storage Code shall mean the Code of the Gas Storage Facilities approved by Order of the Regulator No. 2495 dated 30.09.2015.

GDN Operator means a business entity that has been carrying out operations, subject to its license, which are related to the distribution of natural gas via gas distribution system in favor of third parties (clients).

TSO or GTS Operator shall mean LLC "Gas Transmission System Operator of Ukraine" that has been carrying out operations, subject to its license, which are related to the transmission of natural gas via gas transmission system in favor of third parties (clients).

Gas Storage Operator shall mean a branch "Gas Storage Facilities Operator of Ukraine" of JSC "Ukrtransgas" that has been carrying out operations, subject to its license, which are related to the storage (injection, withdrawal) of natural gas, using one or several gas storage facilities, in favor of third parties (clients).

Tax Code shall mean Tax Code of Ukraine No. 2755-VI, dated 02.12.2010.

Customs Code shall mean Customs Code of Ukraine No. 4495-VI, dated 13.03.2012.

Order No. 629 shall mean Order of the Ministry of Finance No. 629 dated 30.05.2012 On the Customs Formalities Related to the Pipeline Transport and Powerlines.

II. LIST OF ISSUES, FACTS, AND ASSUMPTIONS

This Memorandum analyzes terms and requirements of the effective laws of Ukraine governing injection of biomethane into the gas distribution or gas transmission system, and its further transportation as a commodity from Ukraine to the EU, specifically:

a. Conditions and requirements for connection of biomethane producers to the gas distribution and gas transmission systems and injection of biomethane into such systems and gas storage facilities in accordance with the Law of Ukraine On the Natural Gas Market, the Gas Transmission System Code, and the Gas Distribution System Code as well as other regulations governing natural gas market, including licensing requirements, agreements with operators of gas distribution, gas transmission systems, and gas storage facilities, reporting, etc. However, this analysis does not cover the construction and operation of biomethane production facilities in general, being limited only to the issue of connection to the systems, injection, and storage of biomethane.
b. Conditions and requirements set with respect to the producers and sellers of biomethane for the sale of biomethane to foreign companies and transportation of biomethane as a commodity from Ukraine to the EU under gas purchase and sale agreements, in accordance with the Law of Ukraine On the Natural Gas Market, the Gas Transmission System Code, and the Gas Storage Code as well as other regulations governing the natural gas market, including licensing requirements, agreements with gas transmission system operators and gas storage facilities, transaction documentation, reporting, etc.
c. The applicable tariffs and costs related to the services of connection to the gas transmission and distribution systems, storage and transportation of biomethane in accordance with the Law of Ukraine On the Natural Gas Market, the Code of Gas Transmission System, and the Code of Gas Storage Facilities as well as other regulations governing the natural gas market.
d. Analysis of the customs formalities related to biomethane exports in accordance with the Customs Code of Ukraine and tax implications for the exporters.
e. Formation of the list of legal issues and barriers for injection of biomethane into natural gas systems, its transportation, and further export from Ukraine to the EU, based on legal analysis and comments provided by technical/economic advisers, as well as recommendations for resolving such issues pursuant to the effective laws of Ukraine.

Our analysis below is based on the facts and assumptions set forth above. In this Memorandum, we do not analyze any specific operation with biomethane.

II. ANALYSIS

1. Conditions and requirements for connection of biomethane producers to GDN and GTS as well as injection of biomethane into such systems and Gas Storage Facilities, including licensing requirements, agreements with Operators of GDN, GTS, and Gas Storage Facilities, reporting, etc.

1.1. <u>General terms for connection to GTS and GDN, injection of biomethane into such systems and storage in Gas Storage Facilities.</u>

On 21.10.2021 the Ukrainian Parliament adopted the Law of Ukraine "On amendments to certain laws of Ukraine on the development of biomethane production", which took effect on 11.11.2021. The said law introduces the definition of "biomethane" regulating it as a biogas, which in its physical and chemical characteristics corresponds to the regulations on natural gas. It also provides for a biomethane register, a procedure for verifying biomethane to ensure its further supply to the GTS, and a procedure for issuing guarantees as to the origin of biomethane and further transactions with them.

Pursuant to the second paragraph of part 1 of Articles 19 and 19-1 of the Gas Law:

Producers of biogas or other types of gas from alternative sources have the right to gain access to the gas transmission and distribution systems, gas storage facilities, LNG installations and to connect to the gas transmission and distribution systems, subject to compliance with technical regulations and safety requirements in accordance with the effective laws and provided that biogas or other types of gas from alternative sources comply with the natural gas regulations in terms of their physical and chemical characteristics.

The provisions of the Gas Law shall apply on a non-discriminatory basis to biogas or other types of gas from alternative sources, if biogas or other gas from alternative sources meets the requirements for access to gas transmission and distribution systems, gas storage facilities, LNG installations.

Thus, the laws provide for the possibility to supply purified biogas to GTS or GDN, and store it in the Gas Storage Facilities.

According to the GTS Code, natural gas supplied to GTS must meet the following requirements[1]:

No.	Characteristics	Value
1.	Methane content (C_1), mol. %	≥ 90
2.	Ethane content (C_2), mol. %	≤ 7
3.	Propane content (C_3), mol. %	≤ 3
4.	Butane content (C_4), mol. %	≤ 2
5.	Content of pentane and other heavier hydrocarbons (C_5 +), mol. %	≤ 1
6.	Nitrogen content (N_2), mol. %	≤ 5
7.	Carbon content (CO_2), mol. %	≤ 2
8.	Oxygen content (O_2), mol. %	$\leq 0,02$
9.	Higher heating value (25°C/20°C)	min 36.20 MJ/m^{-3} (10.06 kWh/m^{-3})
		max. 38.30 MJ/m^{-3} (10.64 kWh/m^{-3})
10.	Higher heating value (25°C/0°C)	min 38.85 MJ/m^{-3} (10.80 kWh/m^{-3})
		max. 41.10 MJ/m-3 (11.42 kWh/m^{-3})
11.	Lower heating value (25°C/20°C)	32.66 MJ/m^{-3} (09.07 kWh/m^{-3})
		34.54 MJ/m^{-3} (09.59 kWh/m^{-3})
12.	Dew point temperature at humidity (°C) at an absolute gas pressure of 3.92 MPa	$\leq$ -8
13.	Dew point temperature for hydrocarbons at a gas temperature not lower than 0 °C	$\leq$ 0°C
14.	Content of mechanical impurities:	none allowed
15.	Hydrogen sulfide content, g/m^{-3}	$\leq 0,006$
16.	Mercaptan sulfur content, g/m^{-3}	$\leq 0,02$

Natural gas supplied to GDN must meet physical and chemical characteristics of the natural gas standards defined by the GTS Code[2].

[1] Section 13 (chapter 1) of Article III of the GTS Code.
[2] Pursuant to Section 2 (chapter 1) of Article V of the GDN Code.

Natural gas injected to/withdrawn from/ the Gas Storage Facilities must meet the requirements set out in the GTS Code[3].

Thus, the Client is entitled to have access, and connect, to GTS or GDN, as well as the possibility to transmit biomethane and store it in the Gas Storage Facilities, provided that biomethane meets natural gas standards and other requirements set by the laws governing the natural gas market.

In order to ensure that the clients fulfill their obligations to transmit or store (inject, withdraw) natural gas, the TSO and Gas Storage Operator have the right to demand financial security from the Client, in particular, in the form of guarantees.

Natural gas transmission services are provided subject to a 100% prepayment in the amount of the cost of allocated capacity (for the period of a gas month, quarter and/or year) or in the amount not less than the cost of access to capacity for a gas day, which is planned to be used according to the nomination (for a period of one gas day).

Operators of GDN, GTS, and Gas Storage Facilities may deny the Client's access to GTS or GDN, Gas Storage Facility if one of the following grounds exists[4]:

1) lack or insufficiency of free capacity;
2) granting access will constitute an obstacle for such operator's performing the special duties assigned to it pursuant to the Law[5];
3) denial of such access is substantiated on the basis of the Regulator's decision[6].

In case of denial of access due to lack or insufficiency of free capacity, TSO, Operator of the Gas Storage Facility, may increase the capacity of GTS, Gas Storage Facilities, provided that such increase is economically justified or that the Client has agreed to reimburse the costs of such Operator incurred as a result of the capacity's increase.

If it is technically feasible to connect the Client's biomethane production facility, and the TSO has a free capacity, the Client may connect its own biomethane production facility directly to GTS. The Client can also connect a facility to GDN if the GDN Operator has a free capacity. The GDN or GTS connection service is a fee-based service and is provided by the Operators of GTS or GDN in accordance with the connection agreement.

Thus, in order to connect the Client's facility to GTS or GDN, transmit biomethane to GTS/GDN and store it in the Gas Storage Facility, the Client needs:
- to obtain permission of the GTS or GDN Operator to connect to the GTS/GDN;
- to enter into a connection agreement with the GTS or GDN Operator, including technical regulations, to formalize rights to the land plots under gas networks from the connection point, to comply with the requirements of construction laws, in particular, to put into operation the internal gas supply network from the connection point, to pay for relevant services and otherwise fulfill requirements of the connection agreement and effective laws of Ukraine. In this case, the relevant operator must perform the above actions for the external gas supply

[3] Pursuant to paragraph 2 of Section 10 (chapter 1) of Article III of the Gas Storage Code.
[4] Pursuant to part 3 of Article 19 of the Gas Law.
[5] Special duties to secure the general public interests may be determined by the Cabinet of Ministers of Ukraine after consultation with the Energy Community Secretariat in exceptional cases and for a specified period. At the current stage, there is no list of such special duties.
[6] Such decision may be adopted by the Regulator pursuant to the special rules of access in the instances of existence of the take-or-pay obligation under Article 55 of the Gas Law.

networks, install a metering unit at the measuring point, connect external and internal gas supply networks, and commence gas injection;
- to obtain Energy Identification Code (EIC code);
- to enter into a technical agreement regarding conditions of receipt and transmission of gas with the GTS and/or GDN Operator.
- to enter into transmission agreement with the TSO for access to facilities, gas transmission services, including actions to settle daily imbalances in the GTS;
- to enter into natural gas storage agreement (injection to/withdrawal from the Gas Storage Facilities) with the Gas Storage Operator for gas storage in the Gas Storage Facilities and injection to/withdrawal from, the Gas Storage Facilities;
- to order, and pay for, capacity allocation (at internal entry/exit points and/or interstate connection points), transmission, storage (injection, withdrawal) services, to provide financial security, and to fulfill other obligations under the gas transmission and storage agreements and effective laws;
- to submit appropriate nominations/re-nominations for gas transmission through the TSO IT platform, and for gas injection, withdrawal from the Gas Storage Facilities through the IT platform of the Gas Storage Operator;
- to submit reports regarding operations in the natural gas market.

Detailed procedures for the Client's connection to GDN, GTS, and the procedure for obtaining gas transmission and storage services are given below.

1.2. Procedure and terms for the Client's connection to GTS.

The GTS Code determines that connection to GTS is possible when one of the below conditions is met:
- denial of the client by the GDN Operator due to lack or insufficiency of free capacity;
- the client is a gas producing company that connects natural gas (biogas) extraction/production facilities;
- if the client ordering connection is the Gas Storage Operator;
- if the client is the GDN Operator, whose territorial boundaries of the licensed activity are as close as possible to the connection point;
- if the pressure required to meet the client's needs exceeds 1.2 MPa.

In order to connect a construction site or an existing facility to GTS and receive transmission services, the Client needs to:

1) Obtain connection permit from the TSO.

To obtain such permission, the Client must submit to the TSO a completed and signed application for connection of the Client's facility to GTS and pay the cost of services for connection permission, connection agreement, and technical regulations.

The application is made in an arbitrary form, and the following documents should be attached to it:
- completed questionnaire in the form of the TSO, which contains the technical parameters of the Client's facility to be connected to GTS;
- copies of documents confirming that the Client ordering connection has the right of ownership, or use, of the facility that is planned to be connected, or of the land plot where it is planned to build such facility;
- copies of the Client's documents confirming the powers vested with the representative in order to enjoy the right to enter into the connection agreement (certified by the authorized person:

copies of the articles of association, order appointing the executive, minutes of the founders' meeting regarding appointment of the executive, copy of a power of attorney, copy of documents for signature verification);
- draft act and scheme for the parties' division of balance sheet attribution and operational responsibility.

At the request of the TSO, originals of these documents are presented for review.

In case of connection of the Client's facility to the gas networks which are not owned by the TSO, but are connected to its gas transmission system and which, as a result of connection of the Client's facility, will acquire the status of GTS, the owner of such gas networks should give its written consent to the connection of the Client's facility to its gas networks. Prior to gas injection to the Client's facility, the owner of such gas networks shall enter into an agreement with the TSO (agreement of intentions, memorandum, etc.) regarding the obligation to enter with the TSO into one of the agreements for use of the gas networks (operational management, use or operation) or to transfer ownership thereof.

In the absence of comments regarding the documents submitted or after such comments are considered, the TSO shall review an application for connection and supporting documents within 10 business days.

The templates for the application, form of the questionnaire are available on the TSO's website at the link.

2) Enter into connection agreement with the TSO.

After payment by the Client of the cost of services for granting the connection permit, connection agreement, and technical regulations, the TSO shall provide Client with connection permit, a draft connection agreement in two counterparts, and technical regulations.

The GTS Code does not approve the form of the GTS connection agreement. According to the information received from the representative of the TSO, the draft agreement and technical regulations are provided directly at the Client's request.

3) Perform design and construction works for the external and internal gas supply.

The Client has the right to choose the TSO and/or another company entitled to carry out relevant activity, as a contractor for performance of the connection works.

After entering into the connection agreement, the contractor in charge of performance of design works of the external gas supply on the basis of technical regulations for connection shall provide for:

– obtaining urban planning conditions and restrictions on development of the land plot under external gas supply networks (if necessary);
– performance of engineering and geodetic surveys;
– development and approval of design and estimate documentation for external gas supply networks.

If the contractor of external gas supply works is the Client (including the design organization chosen by the Client), it approves the design and estimate documentation for external gas supply pursuant to technical regulations with TSO. Thereupon, it shall approve the design and estimate documentation, and submit one counterpart thereof to TSO.

In the absence of comments, the design and estimate documentation for external gas supply is to be approved by TSO within 15 days.

After approval of the design and estimate documentation for external gas supply, within 10 business days, TSO is to send to the Client a supplementary agreement to the connection agreement, which determines the time frame for ensuring connection and a connection fee.

If the Client appoints TSO as contractor for the connection works, TSO, in particular, ensures:

- formalization of legal matters pertaining to the land under the external gas supply networks;
- obtaining permits for commencement of the construction works;
- construction and commissioning of newly built (reconstructed) external gas supply networks;
- installation of the metering unit at the connection point (at the Client's request);
- renewal of the amenities damaged as a result of construction;
- connection of the external gas supply networks in the place where capacity is allocated;
- connection of the Client's internal gas supply networks to GTS at the connection point;
- commencement of gas injection to the Client's facility.

If the Client provides for preparatory, design, construction, installation, and commissioning works required for connection to GTS, independently and at its own expense, the cost of these works is not included into the connection service fee.

Within 10 business days after the Client provides supporting documents for commissioning of the internal gas networks, and subject to the Client's payment of the connection fee, the TSO shall ensure connection of the Client's internal gas networks to GTS, unless the connection agreement provides for a later date.

When connecting facilities (installations) of gas producing companies and producers of biogas or other types of gas from alternative sources, the TSO shall organize installation of a commercial metering unit, as well as devices that will continuously monitor physical and chemical parameters of gas (including chromatography recorder, gas density gage, dew point meter, etc.) with the possibility of their remote control, data transmission, and disconnection of low-quality gas supply to the GTS.

The Client may order the service related to installation and outfitting of a commercial metering unit from another company, which is entitled to carry out relevant activities.

The measures related to connection to GTS and construction of gas networks must be carried out in compliance with the Law of Ukraine On Legal Regime of the Lands of Protected Areas of Main Pipelines, the Rules of safety of gas supply systems approved by Order of the Ministry of Energy and Coal Industry of Ukraine, dated 15 May 2015, No. 285, and Rules for safe operation of main gas pipelines, approved by Order of the State Committee of Ukraine for Industrial Safety, Labor Protection, and Mining Supervision, dated 27 January 2010, No. 11.

Gas injection to the Client's facility is carried out by the TSO within 10 business days provided that the natural gas transmission agreement is concluded *(see Section 1.4 of Article 1 of the Procedure and terms for gas transmission through GTS)*.

After the TSO provides the connection service to the Client, the parties shall execute the service delivery and acceptance certificate.

4) Enter into technical agreement on the terms of transfer-acceptance of natural gas.

In order to ensure metering of the gas received and transmitted at entry and exit points, the Client shall enter with the TSO into technical agreement providing for the terms of transfer-acceptance of natural gas[7].

The draft technical agreement is available on the TSO's website at the link (in Ukrainian only).

According to the GTS Code, the transfer-acceptance of natural gas between the TSO and the adjacent gas producing company shall be carried out in compliance with the requirements of the GTS Code, technical agreement, and shall be formalized by delivery and acceptance certificates signed by the parties no later than the 5th day of the month following the month under review.

1.3. Terms and conditions of connection to GDN.

In order to connect a construction site or an existing facility to GDN, the Client needs to:

1) Obtain a connection permit from the GDN Operator

To obtain such permit, the Client must file its application with the relevant GDN Operator and pay the cost of services for granting connection permit, connection agreement, and technical regulations.

The following documents shall be attached to the application regarding connection:

- completed questionnaire in the form approved by the GDN Operator, which contains technical parameters of the Client's facility to be connected to GDN;
- copies of documents defining the Client's right of ownership or use of the facility (premises), and/or a copy of the document confirming the right of ownership or use of the land plot (along with graphic plan of the land plot[8]);
- copies of the Client's documents:
  - identifying the individual or his/her representative (for individuals);
  - certifying the status of a legal entity or individual entrepreneur and its representative (for legal entities and individual entrepreneurs);
  - confirming registration with the State Tax Service in compliance with the requirements of the Tax Code of Ukraine;
  - a copy of the duly executed power of attorney issued in the name of the Client's representative authorized to represent the Client's interests during the connection procedure (if necessary).

To connect the Client's facility to gas networks which are not owned by the GDN Operator and are connected to its GDN and which, as a result of connection to the Client's facility will acquire the status of GDN, the GDN Operator is obliged to apply to the owner of these gas networks for its written consent to the connection of the Client's facility to its gas networks. The Client has the right to apply on its own for consent of the owner of the gas networks. An agreement (agreement of intentions, memorandum, etc.) shall be entered into by and between the owner of these networks and the GDN Operator regarding the owner's obligation to enter into one of agreements for use of gas networks (operational management, use or operation).

[7] Pursuant to Section 9 (chapter 2) of Article III of the GTS Code.
[8] If there is no graphic plan of the land plot (there is no cadastral plan) among the land plot documents, the Client must provide the GDN Operator with general layout plan (scheme) regarding location of the Client's land plot, with its boundaries determined therein.

In the absence of comments with respect to the documents submitted or after such comments are considered, the GDN Operator shall within 10 business days provide the Client with a connection permit, a draft connection agreement, draft technical regulations required for connection and relevant invoices for making payment due for the above.

2) Enter into connection agreement with the GDN Operator

The connection agreement and technical regulations required for connection shall enter into full force and effect as of the date of their return to the GDN Operator in the form of the documents signed by the Client and subject to payment of the costs related to providing the Client with a connection permit, connection agreement, and technical regulations required for connection.

Depending on capacity of the Client's facility and the connection distance, the GDN Operator determines the type of connection to which the Client's facility (land plot) is eligible: standard[9] or non-standard[10].

The form of agreement for standard and non-standard connection, technical regulations for connection are given in annexes 15, 16, 17 to the GDN Code (in Ukrainian only).

3) Perform design works as well as external and internal gas supply works

The Client has the right to choose, at its discretion, a contractor for performance of design and construction works related to the connection, among the entities that have the right to carry out the relevant type of activity.

1. If the Client's facility (land plot) is eligible for the type of connection, which is standard, and the Client appoints the GDN Operator as a contractor for the external gas supply design and construction works, in such instances, a connection point for the Client should be determined at the boundary of the Client's land plot or, subject to the Client's consent, within the territory of such land plot.

After entering into connection agreement, the GDN Operator shall ensure connection of the Client's facility (construction of external gas supply networks from the place of provision of capacity to the connection point) within three months, taking into account the requirements of the GDN Code and the Client's payment schedule pursuant to the agreement.

2. If (i) the Client's facility (land plot) is eligible for a type of connection that is not standard, and the Client appoints the GDN Operator as a contractor of external gas supply works (regardless of the contractor for development of the external gas supply project), or (ii) the Client's project (land plot) is eligible for a type of connection, which is standard, but the Client identifies itself as contractor for the external gas supply project, and the GDN Operator as contractor for construction of the external gas supply networks (gas networks to the Client's land plot), in such instances, the connection point for the Client must be determined at the border of the Client's land plot or, with its consent, within territory of such land plot.

After entering into the connection agreement, the contractor for development of the external gas supply project on the basis of the technical regulations for connection shall provide for:

[9] Connection to GDN of the facilities with a capacity of up to 16 cubic meters per hour to a distance not exceeding 25 m for rural and 10 m for urban areas in a straight line from the point of provision of capacity to the point of connection.
[10] Connection to GDN of the facilities with a capacity exceeding 16 cubic meters per hour to at a distance exceeding 25 m for rural and 10 m for urban areas in a straight line from the point of provision of capacity to the point of connection.

- obtaining urban planning conditions and restrictions on development of the land plot under external gas supply networks (if necessary);
- performance of engineering and geodetic surveys;
- development and approval in accordance with the established procedure of the external gas supply project and its part pertaining to estimates.

If the development of the external gas supply project was provided by a business entity other than the GDN Operator, the specified project and its part related to estimates must be approved by the GDN Operator.

In the absence of comments, the external gas supply project shall be approved by the GDN Operator within 15 calendar days.

After approval of the external gas supply project and its part related to estimates in accordance with the procedure established by law, the GDN Operator shall send to the Client a supplementary agreement to the connection agreement within 10 business days, specifying the time frame for connection of the Client's facility to GDN and the respective connection fee.

If the Client appoints the GDN Operator as contractor, the GDN Operator shall, in particular, provide for:

- obtaining urban planning conditions and restrictions on development of the land plot under the external gas supply networks (if necessary);
- performance of engineering and geodetic surveys;
- development and approval of the external gas supply project and its part related to estimates;
- registration of land relations with respect to the route of laying of the external gas supply networks;
- obtaining permits for commencement of construction works;
- construction and commissioning of newly built (reconstructed) external gas supply networks;
- installation of the metering unit at the measuring point (at the Client’s request);
- renewal of the amenities damaged as a result of construction;
- connection of external gas supply networks in the place of provision of capacity;
- connection of the Client's internal gas supply networks at the connection point;
- commencement of injection of gas to the Client’s facility.

By the parties’ consent, the connection agreement may specify a longer or shorter time frame for implementation of these measures, including the period required by the GDN Operator to agree and formalize the right to use the land plot under the external gas supply networks in compliance with the procedure determined by the effective laws.

3. If the Client appoints another business entity (other than GDN Operator) as contractor for the construction works related to such connection, the connection point shall be defined in the existing GDN of the GDN Operator and coincides with the place of provision of capacity, from which the Client is to construct the internal gas supply networks in accordance with the design premises of the GDN Operator, which are defined in the technical regulations for connection.

In this case, the measures implemented by the GDN Operator under the connection agreement and the cost of the service of the GDN Operator for connection of the Client’s facility (connection fee) shall include:

- purchase, installation, and commissioning of the metering unit at the measuring point;

- development of the external gas supply project (if necessary and in case of appointment of the GDN Operator as contractor for development of this project);
- connection of the external gas supply networks in the place of provision of capacity (if any);
- connection of the Client's internal gas supply networks at the connection point;
- commencement of injection of gas to the Client's facility and entering into natural gas distribution agreement (technical agreement).

After signing of the connection agreement, the Client acting in the manner prescribed by law, shall ensure:

- formalization of land relations regarding the route of laying gas networks to be constructed by the Client from the point of connection;
- obtaining urban planning conditions and restrictions on the land plot development from the point of connection (if necessary);
- performance of engineering and geodetic surveys;
- development of the internal gas supply project taking into account the requirements of the GDN Code;
- obtaining permits in the manner prescribed by law to begin construction works;
- performance of preparatory and construction works for laying of the internal gas supply networks from the point of connection;
- commissioning, in the manner prescribed by law, of the internal gas supply networks from the point of connection;
- renewal of amenities damaged as a result of construction.

If the Client provides for performance of the preparatory, design, construction, installation, and commissioning works required for connection to the GTS, independently and at its own expense, the cost of these works shall not be included into the connection service fee.

4. On the basis of design data for design of the internal gas supply networks, which are defined in technical regulations for connection, the Client shall provide, in compliance with the procedure established by the effective laws, and its own expense, for development of the project of internal gas supply as well as construction and commissioning of the internal gas supply networks from the point of connection to its own gas devices and equipment.

If technical regulations for connection define the measuring point (location of the commercial metering unit) to be within the internal gas supply networks, the internal gas supply project should provide for the measures aimed at installation of the metering unit as well as for estimates related to the implementation of such measures, and such project for internal gas supply in terms of installation of the metering unit as well as estimates required for such installation, should be approved by the GDN Operator. Within 15 days, the GDN Operator shall either approve it, or provide the extensive list of its comments (if any) thereto.

5. Within 10 business days in urban areas and 15 business days in rural areas after commissioning of the internal gas supply networks, the GDN Operator shall be obliged to ensure connection of the Client's facility to GDN (physical connection of external and internal gas supply networks), provided that the Client paid the cost of such connection service and unless the connection agreement determines a later date.

When connecting facilities (installations) of gas producing companies and producers of biogas or other types of gas from alternative sources, the GDN Operator shall arrange for installation of a commercial metering unit, as well as devices that will continuously monitor physical and chemical parameters of gas (including chromatography recorder, flow density meter, dew point meter, etc.), with possibility of remote control, data transmission, and disconnection of poor quality gas supplies to GDN.

Injection of gas to the internal gas supply networks at the Client's facility shall be commenced by the GDN Operator within 5 business days in urban areas and 10 business days in rural areas subject to availability of the executed technical agreement and after the Client acquires confirmed natural gas volumes for the relevant period.

Construction of the external and internal gas supply networks must be carried out in compliance with legal regime set for lands of the protection zones of main pipelines and gas distribution systems, as well as requirements stipulated by the Rules of safety of gas supply systems, approved by Order of the Ministry of Energy and Coal Industry of Ukraine, dated 15.05.2015, No. 285.

The fact of performance of the service related to the connection of the Client's facility to GDN is the certificate of delivery of the connection service, which is executed by the Operator of GDN and the Client, and such execution shall be initiated by the Operator of GDN. The Client is not entitled to refrain from executing the certificate of delivery of the connection service without good reasons.

The GDN Operator shall acquire ownership of the external gas supply networks, including the metering unit, in accordance with Article 331 of the Civil Code of Ukraine.

4) Enter into technical agreement providing for the GDN terms of transfer-acceptance of gas

In order to transmit gas to/receive it from GDN, producers of biogas or other type of gas from alternative sources should enter into a technical agreement with the GDN Operator (to which their facilities are connected) subject to the terms of the GDN gas transfer-acceptance[11].

In order to enter into such technical agreement, the Client must have an EIC code. In its absence, such code is received simultaneously with execution of the technical agreement.

The form of the technical agreement is set forth in Annex 2 to the GDN Code (in Ukrainian only).

The technical agreement providing for the terms of the GDN gas transfer-acceptance shall contain:
- personal EIC code of each party;
- parameters of natural gas quality and procedure for determining physical and chemical parameters (PCP) of natural gas;
- certificate confirming the parties' division of balance sheet attribution and operational responsibility pursuant to the scheme of gas flows to the GDN (Gas Loss Measuring Point));
- list of commercial and back-up gas metering units (Instrumentation Equipment);
- procedure for commercial metering of natural gas (procedure for determining the volume of natural gas transmitted to/from GDN);
- procedure for checking commercial gas metering units;
- procedure for the parties' interaction in case of emergencies;
- procedure for obtaining baseline information from commercial or back-up gas metering units.

Under the technical agreement stipulating the terms for the GDN gas transfer-acceptance, no payments are made for natural gas between the parties.

[11] Pursuant to the second paragraph of Section 2 (chapter 1) of Article VI of the GDN Code.

5) Conclude a natural gas distribution agreement (if necessary).

In the event that the Client needs to obtain gas from GDN, it must enter into a natural gas supply agreement with the relevant supplier and a gas distribution agreement with the GDN Operator.

The agreement for supply of natural gas to non-domestic consumers (including biogas producers and other industrial consumers) is concluded in compliance with the requirements of the effective laws of Ukraine[12]. The draft agreement is posted on the website of the relevant supplier (example, in Ukrainian only).

In addition, the Client must enter into natural gas distribution agreement with the GDN Operator by signing an application for connection. A standard natural gas distribution agreement is concluded according to the form approved by the Regulator.

1.4. Procedure and terms for gas transmission through GTS

Regardless of whether the Client's facility is connected to GDN or directly to GTS, in order to gain access to capacity, receive the service of natural gas transmission through GTS, including daily imbalances settlement services in GTS, the Client needs to:

1) Have/obtain EIC-code

To enter into a transmission agreement, the Client must have an EIC code. In case of its absence, an application for receiving the code can be submitted together with the application for conclusion of the transmission agreement.

To obtain the EIC-code, the Client provides the TSO with:

- application for EIC-code;
- application for placement on the website of ENTSO-E (European Network of Transmission System Operators for Electricity) for carrying out export and import operations.

If the EIC code issued by the GDN Operator is available, the Client provides:

- application for registration of EIC code on the TSO Information Platform;

Sample applications for EIC code assignment are available on the TSO website at the link.

2) Enter into transportation agreement with TSO.

To enter into the transportation agreement, the Client provides the TSO with the following:

- application for entering into the transportation agreement;
- in case the Client of transmission services is a non-resident of Ukraine, a document confirming its registration as an economic entity in the country of its permanent location shall be additionally submitted;
- scanned copies of documents confirming the representation powers vested with the respective persons, including performance of transactions, which are certified by the Client's authorized person (should be sent to the e-mail: commercial@tsoua.com):
    - Scanned copy of the Client's articles of association;

[12] In accordance with the fourth paragraph of Section 3 of Article I of the Rules for the supply of natural gas, approved by the Regulator's Resolution No. 2496, dated 30.09.2015.

    - Excerpt from the Unified State Register of Legal Entities and individuals – entrepreneurs (Commercial Register / State Register – for Clients – non-residents of Ukraine). The Excerpt should be received no later than one month before the date of contract conclusion;
    - Scanned copy of the order appointing the Client's executive;
    - Scanned copy of the minutes of the founders' meeting regarding appointment of the Client's executive;
    - Certified scanned copies of documents for signature verification;
    - Scanned copy of the signatory's power of attorney.
- originals of the agreement in two counterparts: completed, signed, and sealed by the Client.

The Client's documents must be duly certified by the Client's authorized person. The certification mark on a copy of the document shall consist of the words "*Complies with the original*", position, personal signature certifying the copy, his/her initials and last name, and the date of certification of such copy. In case the documents were executed in a foreign language, their certified translation into Ukrainian shall also be submitted.

The draft transportation agreement with annexes thereto and other information pertaining to the execution of the agreement are available on the TSO website at the link.

The TSO shall review the application for conclusion of the transportation agreement and the documents attached thereto within 10 days. As a rule, the TSO adheres to this deadline, but in case of additional questions, entering into such agreement may take longer.

According to the transportation agreement, the TSO also provides services related to settlement of daily imbalance at the actual cost, which is determined in accordance with the procedure established by the GTS Code *(see Section 3.2 of Article 3: Tariffs and costs associated with gas transmission services via GTS).*

3) Create an account on the information platform of the TSO.

In order to work on the Information Platform, it is necessary:

- to get access to the platform by creating an account.
- to register the right to sign documents (Electronic Digital Signature - ECDS) submitted through the information platform.

To gain access to the platform, the Client must provide TSO with the following documents:
- The original notification regarding creation (deletion or adjustment) of the account of the authorized representatives of the platform user (Annex 1 to the GTS Code).
- Power of attorney for authorized persons who have the right to access the information platform on behalf of the platform user (except for the executive acting on the basis of the articles of association).
- The original power of attorney for the persons authorized to sign documents submitted through the information platform on behalf of the platform user, including persons who have a power of attorney for access to the information platform.
- Notification on provision of specimen of digital signatures.

Detailed instructions on how to access the platform are available on the website of the TSO at the link.

4) Obtain a shipper code

In order to ensure performance of standard procedures for coordination, distribution, balancing, and logging of natural gas volumes at the interstate connections with operators of adjacent gas transmission systems, the Client must be assigned a shipper code.

For this purpose, the Client shall provide TSO with:

- application for assigning / registering a shipper code;
- shipper pair's registration form.

Forms of the documents are available on the website of the TSO at the link.

5) Issue financial security or make an advanced payment for the transmission services

1. In order to ensure that the Client fulfills its obligations to pay for the daily imbalance settlement services of natural gas supplied to, and withdrawn from, the GTS, the Client must provide financial security in the amounts specified in the GTS Code.

Such financial security shall be issued in one or several forms listed herebelow:
– bank guarantee (the issuing bank should comply with certain requirements);
– payment due to the TSO on the basis of the natural gas transportation agreement.

Financial security is not required from the Client receiving transmission services who has a long-term credit rating not lower than "BBB" confirmed by the Standard & Poor's and/or Fitch IBCA, and/or not lower than "Baa2" confirmed by the Moody's Investors Service.

For the Client (gas producing company), such amount of sufficient financial security is reduced by the cost of the daily volume of production, which is the lowest for the last three calendar months according to the gas supply allocations of the gas producing company.

Detailed information on financial security, a sample of the bank guarantee, and a calculator for calculation of financial security are available on the website of the TSO at the link.

2. Natural gas transmission services shall be provided subject to 100% advance payment in the amount of the allocated capacity (for the period of a gas month, quarter and/or year) or in the amount not less than the cost of access to capacity for the period of a gas day, which is planned to be used pursuant to nomination (for a period of one gas day).

6) Place an order for the respective services

To order transmission services, the Client must pre-order, and pay for, the appropriate capacity at entry/exit points at the domestic and/or interstate connections.

In order to participate in the capacity allocation procedure (annual, quarterly, and monthly) at the internal entry/exit points for the respective gas year, it is necessary to submit the relevant applications (in the form of Annex 1 to the natural gas transportation agreement) within the time frames specified by law. Ordering capacity per day shall occur during submission of a nomination. The calendar of distribution of capacity at the internal entry/exit points to/from the GTS for the gas year 2020-2021, the gas year 2021-2022, and the next fourteen gas years, as well as the application submission deadlines are available on the website of the TSO at the link.

Ordering capacity at the interstate connections, in addition to ordering interruptible capacity for a day, as well as capacity with restrictions, is done through auctions on RBP and GSA platforms. After the auction, annual, quarterly, and monthly capacity is allocated by submitting an annex to the agreement.

Payment for the contracted capacity is made subject to 100% prepayment within the time frames that depend on the type of auction and the type of capacity order (annual, quarterly and monthly/per day in advance/during the day).

The order for transmission services is made by submitting appropriate nominations/re-nominations for gas transmission through the IT platform of the TSO.

1.5. Procedure and terms for storage of the Client's biomethane in the Gas Storage Facilities.

For storage of biomethane in the Gas Storage Facilities, the Client should:

1) Enter into storage agreement with the Gas Storage Operator

To enter into an agreement for storage (injection, withdrawal) of natural gas, the Client provides the Gas Storage Operator with:

- application for entering into the storage agreement;
- EIC-code;
- documents confirming the powers vested with the respective persons representing the Client's company, including performance of transactions (Client's articles of association, power of attorney, etc.);
- questionnaire of the counterparty - legal entity;
- consent to the processing of personal data.

Application forms, draft agreement, and other information for entering into the storage agreement are available on the website of the Gas Storage Operator at the link.

Please note that the precondition for entering into the storage (injection, withdrawal) agreement is availability of the executed natural gas transmission agreement with the TSO.

The Client may apply for capacity allocation at the same time as the application for concluding a storage (injection, withdrawal) agreement.

The Gas Storage Operator shall review an application for entering into the gas storage (injection, withdrawal) agreement and the documents attached thereto, within 10 days. In the case of simultaneous submission of an application for entering into the storage agreement and an application for capacity distribution, the storage agreement is concluded only if the parties consent to distribution of the capacity.

2) To create an account on the Information Platform of the Gas Storage Operator

In order to be able to work on the Information Platform, it is necessary:

– to gain access to the platform by creating an account.

– to register the right to sign documents (Electronic Digital Signature) submitted through the information platform.

In order to gain access to the platform, the Client should provide the Gas Storage Operator with the following documents:

– application for the creation of account for the authorized persons of the I-platform user;
– written Power of Attorney for each authorized person, acquiring the right to access the I-platform on behalf of the platform user;
– Power of Attorney for the persons who have the right to sign documents submitted through the I-platform on behalf of the platform user;
– notice regarding signature of the user in the person of the direct manager of such entity.

Detailed instructions on how to access the platform are available on the website of the Gas Storage Operator at the link.

3) Order respective services

To receive the services related to gas injection, storage, and withdrawal from the Gas Storage Facilities, the Client must pre-order the relevant annual or monthly capacity (if the Client has not submitted an application together with the application for the storage agreement) through the IT platform of the Gas Storage Operator and/or send its application in paper form.

The Gas Storage Operator publishes daily information on its website in relation to the allocated and free capacity of the Gas Storage Facilities, calculations regarding online injection/withdrawal curves and a calculator for calculating the cost of booked capacity.

The gas injection, storage, and withdrawal services in the Gas Storage Facilities is ordered by submitting respective nominations/re-nominations for gas injection/withdrawal through the IT platform of the TSO and the IT platform of the Gas Storage Operator.

1.6. Licensing terms applicable to the business operations in the natural gas market.

According to the Gas Law, the following activities are subject to licensing[13]:

- transmission of the natural gas through the GTS for the benefit of third parties;
- storage (injection, withdrawal) of natural gas using one or more Gas Storage Facilities for the benefit of third parties (clients);
- provision of LNG installation services for the benefit of third parties (clients);
- supply of natural gas: business operations that are subject to licensing and consist in the sale of natural gas directly to consumers on the basis of agreements concluded with them;
- distribution of natural gas: business operations that are subject to licensing and related to the transmission of the natural gas through GDN for the purpose of its physical delivery to consumers, but which does not include the supply of natural gas.

In the instances when gas is sold or transmitted for the purpose of its sale/delivery to consumers in the territory of Ukraine, the Client is obliged to obtain a license from the Regulator and comply with the relevant license terms posted on the Regulator's website.

In particular, the Client's operations may be eligible for supply of natural gas when the gas produced is directly sold to consumers. According to the Gas Law, a consumer is an individual, individual entrepreneur or a legal entity that receives natural gas on the basis of an agreement for the supply of

[13] Pursuant to Article 1 of Section 1 of the Gas Law.

natural gas for its own use, rather than for resale or use as a raw material. Licensing terms for conducting business operations related to the supply of natural gas, define the territory of Ukraine as the place of conducting such business operations.

If the Client's operations are eligible for the licensed operations related to the natural gas supply, it will be obliged to create an insurance reserve of natural gas, the amount of which is set annually by the decision of the Cabinet of Ministers of Ukraine. In 2021, there is no obligation to create an insurance reserve, but the Gas Law provides for the possibility of setting it at the level of up to 10 percent of the planned monthly supply of natural gas to consumers for the next month.

In the instances when the Client produces biomethane, sells it to another business entity (non-resident) on the basis of purchase and sale agreements not for its own consumption and further export to the EU countries, such activities of the Client will not require a license. If a non-resident plans to use biomethane for its own needs or as a raw material, formally, the producer of biomethane may be required to obtain a license to supply natural gas, as the Gas Law does not expressly state that only Ukrainian residents can be consumers. However, it is established in the preamble of the Gas Law that such Law determines a legal basis for functioning of the specific market: natural gas market of Ukraine. Thus, it can be argued that the supply of gas to consumers outside the territory of Ukraine should not be governed by the Gas Law. To reduce the risk of recognizing this transaction as requiring the availability of the Client's gas supply license, we recommend that you should obtain relevant explanations from the Regulator.

1.7. Reporting of the gas producing companies.

1) The business entities operating in the natural gas market (except for consumers) are obliged to prepare reports approved by the Regulator with respect to each type of the business operations in the natural gas market, which is subject to licensing, and to submit the same to the Regulator, along with the annual financial statements[14].

In the instances when the Client carries out activities which are subject to licensing in the territory of Ukraine, the obligations regarding reporting set by the licensing terms shall be applicable to the Client.

In particular, the natural gas suppliers shall enter the below data into the information platform of the TSO[15]:

- the Client's own consumers and periods of natural gas supply to them;
- nominations/re-nominations.

2) Regardless of the fact, whether the Client is to carry out the activities which are subject to licensing, the below reporting requirements shall be applicable to it.

The Client shall be obliged to enter the following data into the TSO information platform subject to the forms of the TSO[16]:

- information regarding its own company connected to the GTS/GDN (form No. 6);

[14] Pursuant to part 2 of Article 57 of the Gas Law.
[15] Pursuant to section 7 (chapter 4) of Article IV of the GTS Code.
[16] Pursuant to section 6 (chapter 4) of Article IV, section 4 (chapter 5) of Article XII of GTS Code.

- information on the volume/amount of natural gas supplies at the virtual entry point (form No. 7).

The gas producing company shall submit to the TSO[17]:

- information pertaining to the results of verification of the conformity of a nomination or re-nomination at the points of entry from the gas producing company (exclusively for the adjacent gas producing company);
- information on the occurrence of interruptions in the gas networks of the gas producing company, which may affect the terms of cooperation with GTS, containing information on the cause of interruptions, their expected duration, reduction of capacity at the GTS connection points, values of parameters that do not meet the contractual terms, confirmation of changed nominations that occur due to such interruptions;
- information on the planned works in the gas networks of the gas producing company, which may affect the terms of cooperation with the GTS, in order to agree with the TSO the possible time frame for, and duration of, the works.

The Client receiving the transmission services, shall submit to the TSO[18]:

- information on planned (ordered) volumes of natural gas transmission;
- nominations and re-nominations of natural gas transmission volumes;
- information on interruptions on the part of the consumer and/or suppliers of the Client receiving the transmission services, which may affect the operating conditions of GTS, including the cause of interruptions, their expected duration, values of parameters that do not meet contractual terms, and issuance of respective re-nominations for volumes, which are changing due to interruptions;
- for entry points and exit points to/from GTS in connections to the gas transmission systems of neighboring countries (interstate connections): every Thursday - no later than 10:00 am – to provide a forecast for daily volumes of natural gas to be submitted for transmission of each gas day next week, from Monday through Sunday.

In addition, the Client is obliged to submit a report regarding its own production and transmission of natural gas to GDN/GTS for a gas month, by the 8th day of the month following the reporting month, in paper or electronic form through the TSO information platform[19].

3) In the instances when gas is sold in the territory of Ukraine/gas exported from Ukraine to the EU, the following reporting requirements shall be also applicable to the Client.

According to the Regulator’s Resolution No. 1234 dated 7 July 2016 *On approval of the Regulator’s reporting forms related to monitoring in the natural gas market, and instructions for their completion*, the business entities operating in the natural gas market, which are engaged in wholesale of natural gas are required to submit the report to the Regulator by the 20th day of the month following the reporting quarter. The report must contain information on the production, wholesale purchase, and sale of natural gas (in thousands of m^3), as well as the wholesale price of purchase and sale of natural gas (UAH per thousand m^3).

The report form assumes that the information is provided for each counterparty, indicating the name of each counterparty. If Form No. 4 contains information and/or data of a confidential nature that

[17] Pursuant to section 4 (chapter 3) of Article XVI of the GTS Code.
[18] Pursuant to section 6 (chapter 3) of Article XVI of the GTS Code.
[19] Pursuant to section 9 (chapter 7) of Article III of the GTS Code.

constitutes a trade secret, in order to ensure the protection of confidential information by the Regulator, the wholesaler shall determine the list of such information, terms, and procedure for its dissemination by the Regulator and submit it together with Form No. 4.

In addition, in accordance with paragraph 7 of Chapter I of Order of the Ministry of Energy and Coal Industry of Ukraine No. 686 dated 02.11.2015 *Rules on security of natural gas supplies*, business entities operating in the natural gas market (except for consumers) shall submit - by May 1 each year - a report on internal documents, providing for the implementation of safety standards for natural gas supply stipulated by the Rules. In general, the standards apply to natural gas suppliers for protected consumers and pipeline owners (GDN, GTS). However, preventive measures determined by the Ministry of Energy and Coal Industry can also be applied to the wholesalers.

Currently, information on preventive measures is available only for 2019/2020, and it obliges all natural gas market participants to comply with gas use rules, technical and other standards, fulfill obligations under relevant gas agreements, etc., as well as notify the Ministry of Energy and Coal Industry of Ukraine of the facts or circumstances that may threaten the security of gas supplies in Ukraine.

2. Conditions and requirements for producers and sellers of biomethane for the sale of biomethane to foreign companies and transmission of biomethane as a commodity from Ukraine to the EU under gas purchase and sale agreements, including licensing requirements, agreements with Operators of GTS and Gas Storage Facilities, transaction documentation, reporting, etc.

In order to sell biomethane to another business entity (non-resident) and to transmit biomethane as a commodity from Ukraine to the EU under gas purchase and sale agreements, the Client needs:

- to have a gas transportation agreement with the TSO;
- for the purpose of selling such gas to the buyer, to enter into an appropriate foreign economic agreement, to order capacity at the interstate connections, and to submit a trade notification to the TSO or the Gas Storage Operator through the appropriate IT platform;
- to prepare and submit a periodic customs declaration and an additional customs declaration;
- to prepare and submit a tax invoice;
- to report the sales of gas to the Regulator, and in some cases, to the Ministry of Energy and Coal Industry of Ukraine, as defined above.

According to the explanations to the Ukrainian Classification of Goods for Foreign Economic Activity (UCGFEA), biomethane (biogas) falls within category 2711 29 00, which includes gas (in gaseous state) obtained from biomass[20].

The rate of duty on the transmission of biogas (biomethane) through the customs border of Ukraine, if classified by the customs authorities as falling into category 2711 29 00, is 0%.

More detailed information on the tax and customs aspects of biomethane sales is given below.

[20] Pursuant to the explanations to the Ukrainian Classification of Goods for Foreign Economic Activity (UCGFEA) approved by Order of the State Customs Service, dated 14.07.2020, No. 256.

2.1. Customs clearance of sales of biomethane as a commodity from Ukraine to the EU.

Transmission of goods through the customs border of Ukraine via pipeline is carried out on the basis of the completed periodic customs declaration[21].

When transmitting goods through the customs border of Ukraine by pipeline, the documents stipulated by paragraph 5 of the first part of Article 335 of the Customs Code of Ukraine[22] are to be submitted to the customs authority:

a) a foreign economic agreement (contract) or other documents confirming the right of possession, use and/or disposal of goods;
b) a certificate of delivery and acceptance of goods or a certificate confirming quantity of goods;
c) commercial and accompanying documents (if available to the owner of the pipeline transport) for the goods transmitted through the customs border of Ukraine, and, at the time of customs clearance, an invoice;
d) name and address of the consignor of the goods;
e) name and address of the consignee;
f) documents (permits, certificates) confirming the relevant parameters pertaining to the goods.

The following documents issued as a result of transmission of goods through the customs border of Ukraine in the relevant customs regime (gas is sold/transmitted from Ukraine) for the previous calendar month may be used as certificate of delivery and acceptance of natural gas:

- certificate of delivery and acceptance of natural gas by carriers[23];
- certificate of delivery and acceptance of natural gas in accordance with the foreign economic agreement (contract)[24];
- general certificate of delivery and acceptance of natural gas by carriers[25];
- certificate of the TSO, attached to the general certificate of delivery and acceptance of natural gas by carriers, signed by the operators of the gas transmission system of Ukraine and the adjacent state, which contains data on the distribution of gas imported into the customs territory of Ukraine, between the business entities engaged in a foreign economic activity;
- general certificate of delivery and acceptance of natural gas between the parties to a foreign economic agreement (contract) for gas transit/import[26] etc.

In addition, together with the customs declaration, an invoice or other document determining the value of goods and, in the instances established by the Customs Code, a declaration of customs value[27]

[21] Pursuant to Section 2.2 of Article II of Order No. 629.
[22] Pursuant to Section 2.5 of Article II of Order No. 629.
[23] Document containing data on the volume of natural gas transmitted through the customs border of Ukraine and delivered through a separate gas reception and transfer point, which is signed by the operators of the gas transmission system of Ukraine and a neighboring state or a party to a foreign economic agreement (contract) for transit/import of natural gas, and operator of the gas transmission system of the adjacent state;
[24] Document containing data regarding amount of the natural gas supplied on the basis of a foreign economic agreement (contract), signed by the parties to a foreign economic agreement (contract).
[25] Document signed by operators of the gas transmission system and the neighboring state or a party to a foreign economic agreement (contract) for transit/import of natural gas and the operator of the gas transmission system of a neighboring state, which contains data on the volume of natural gas transmitted through the customs border (if available, the volumes of balancing of natural gas and the volumes of natural gas under backhaul operations should be stated), indicating the conditional alphanumeric codes for identification of senders and recipients (shipper pairs) of such volumes of natural gas.
[26] Document prepared after expiry of a foreign economic agreement (contract) for the customs clearance pursuant to the relevant customs regime of balancing volumes of natural gas as a result of its transmission via pipeline transport through the customs border of Ukraine.
[27] Pursuant to part 3 of Article 335 of the Customs Code.

shall be submitted to the customs body. In the manner prescribed by the Customs Code, the declarant or its authorized person shall include the below information into the customs declaration:

1) documents confirming the powers vested with the person filing the customs declaration;
2) foreign economic agreement (contract) or other documents confirming the right of possession, use and/or disposal of goods;
3) transportation documents;
4) commercial documents available to the person filing the declaration;
5) if necessary, documents confirming compliance with measures of non-tariff regulation of foreign economic activity;
6) documents confirming compliance with the restrictions caused by the application of protective, anti-dumping, and compensatory measures (if any);
7) in the instances stipulated by the Customs Code: documents confirming the country of origin of the goods;
8) if necessary, documents confirming payment and/or securing payment of customs duties;
9) if necessary, documents confirming the right to benefits in relation to the payment of customs duties, application of full or partial exemption from payment of customs duties in accordance with the selected customs regime;
10) if necessary, documents confirming changes in the terms governing payment of customs duties;
11) if necessary, documents confirming the declared customs value of goods and the chosen method of its determination in accordance with Article 53 of the Customs Code.

By the 15th day of the month following each calendar month of transmission of goods through the customs border of Ukraine according to the periodic customs declaration, the declarant or the person authorized by it is obliged[28]:

- to submit an additional declaration(s) containing accurate information on the goods transmitted through the customs border of Ukraine under the periodic customs declaration in accordance with the declared customs regime during the relevant calendar month;
- to submit the documents required by law, necessary for the customs clearance of goods, except for the documents submitted together with the periodic customs declaration;
- to pay the customs duties that need to be paid during, or as a result of, transmission of goods through the customs border of Ukraine.

In the instances of exporting goods (except for those transported by stationary means of transport) outside the customs territory of Ukraine according to the periodic customs declaration, the calendar month of transmission of goods through the customs border of Ukraine is the month, in which the customs body allowed the goods to be transported outside the customs territory of Ukraine.

2.2. Tax aspects related to biomethane transmission, biomethane storage in the Gas Storage Facilities, and its sale as a commodity from Ukraine to the EU.

The provision of biomethane transmission services via GTS, GDN, and gas storage in the Gas Storage Facilities, which is carried out in the territory of Ukraine by residents of Ukraine, VAT payers, is subject to VAT at a rate of 20%.

The sale of biomethane by a resident of Ukraine to a non-resident (for example, to the EU resident company) is subject to 0% VAT provided that biomethane is exported outside the customs territory of Ukraine pursuant to the customs regime of export, duty-free trade or free customs zone.

[28] Pursuant to Section 26 of Resolution of the Cabinet of Ministers of Ukraine No. 450 dated 21 May 2012, *On Issues Pertaining to the Application of Customs Declarations.*

According to the Tax Code, profit of a legal entity in the general taxation system with a source of origin from Ukraine and abroad is taxed at a standard rate of 18%, which is calculated as a difference between income and expenses incurred during the reporting period in accordance with national regulations (standards) of accounting or international financial reporting standards.

3. Applicable tariffs and costs related to the GTS and GDN connection services, biomethane storage, and transmission.

3.1. Tariffs and costs related to the services of connecting the Client's facility to GDN and GTS.

The cost of connection services provided by the Operator of GDN/GTS consists of the cost of connection of the Client's facility to GDN/GTS and individual services (works) related to the connection and current activity of the Operator of GDN/GTS[29].

Depending on the contractor for design and construction works of the external gas supply networks, some services (works) related to the connection include:
1) granting permission to connect the Client's facility to GDN/GTS;
2) providing technical regulations for connection or reconstruction of the gas metering unit;
3) submission of a draft connection agreement;
4) approval of project documentation for compliance with the provided technical regulations and legislation;
5) technical supervision over the construction of the internal gas supply networks;
6) connection of the external gas supply networks in the place of provision of capacity;
7) connection to GTS or GDN of the internal gas supply networks;
8) commissioning of the metering unit as a commercial metering unit;
9) commencement of injection of gas to the Client's facility;
10) termination (restriction) of transmission or distribution of natural gas;
11) resumption of transmission or distribution of natural gas;
12) registration and supervision of works in the GDN protection zone.

The cost of connection of the Client's facility is determined by the Operator of GDN/GTS in the connection agreement in accordance with the *Methodology for setting a fee for connection to the gas transmission and distribution systems*, approved by the Regulator's Resolution No. 3054, dated 24.12.2015.

The standard connection fee includes, in particular, the service of installing a metering unit at the metering point to ensure its protection from adverse weather conditions and unauthorized access, as well as services for connecting external and internal gas supply networks, and commencement of gas injection. If the Client orders GDN or GTS connection services, organization and installation of a commercial gas metering unit from other entities, the cost of these works is not included into a calculation of the cost of the connection service ordered from the Operator of GDN/GTS.

The cost of standard connection is calculated according to the type of connection, location (rural, urban), ordered capacity for connection, etc. The maximum level of payment for connection, which is standard, to the gas distribution systems for 2021 is approved by the Regulator's Resolution No. 2488, dated 16.12.2020. A standard connection fee calculator is available on the Regulator's website.

[29] In accordance with paragraph 1 of section IV of the *Methodology for setting a fee for connection to the gas transmission and distribution systems*, approved by the Regulator's Resolution No. 3054, dated 24.12.2015.

The maximum level of fee due for the connection, which is non-standard, is determined by the Operator of GDN/GTS in the connection agreement, taking into account:

1) the cost of developing the external gas supply project and its part related to estimates, if the project was developed by the Operator of GDN/GTS;
2) the cost of construction of external gas supply networks;
3) the cost of installation at the point of measurement of the metering unit;
4) the cost of connecting gas networks of external and internal gas supply, as well as the cost of commencement of gas injection.

According to the calculation approved by the TSO, the cost of work pertaining to the development and issuance of technical regulations for connection to the GTS in 2021 is UAH 19,345.32, incl. of VAT (approx. EUR 645).

3.2. Tariffs and expenses related to the gas transmission services through the GTS

From January 1, 2020, the following tariffs for the services of the TSO for natural gas transmission for the regulatory period 2020 - 2024 have been set[30]:

1) Tariffs for natural gas transmission services for entry and exit points to/from GTS at the interstate connections:

No.	Point of entry into the GTS of Ukraine/Point of exit from the GTS of Ukraine	Tariff for the entry point	Tariff for the exit point
		USD per 1,000 cubic meters per day, excl. of VAT	USD per 1,000 cubic meters per day, excl. of VAT
1.	Virtual or physical points (Hermanovichi, Drozdovichi, Ustyluh) at the interstate connection with Poland	4.45	9.04
2.	Virtual or physical points (Budintse, Uzhhorod/Velky Kapushany) at the interstate connection with Slovakia	4.45	9.68
3.	Virtual or physical points (Berehdarots, Berehove) at the interstate connection with Hungary	4.45	9.25
4.	Ananiyiv	-	8.17
5.	Hrebeniky	0.00	8.17
6.	Kaushany	0.00	1.13
7.	Lymanske	4.45	8.17
8.	Oleksiyivka	-	9.71
9.	Orlivka/Isakcha	4.45	1.13
10.	Sokhranivka	16.01	-
11.	Sudga	16.01	-
12.	Tekove/Mediash Aurit	4.45	8.78
13.	Virtual point in the Republic of Moldova	-	0.56

2) Tariffs for the natural gas transmission services for internal entry point to, and exit point from, the GTS:

No.	Point of entry into the GTS of Ukraine/Point of exit from the GTS of Ukraine	Tariff for the entry point	Tariff for the exit point
		UAH per 1,000 cubic meters per day, excl. of VAT	UAH per 1,000 cubic meters per day, excl. of VAT
1.	Entry points with physical location from adjacent gas companies (through the networks of which natural gas of another gas company or group of gas companies can be transmitted)	101.93	-

[30] Pursuant to the Regulator's Resolution dated 24.12.2019, No. 3013 (as thereupon amended).

2.	Virtual entry points with an unspecified physical location from the GDN (place of gas supply from the gas producing company at the point of its connection to the GDN, through which, inter alia, gas of another gas producing company or group of gas producing companies may be transmitted)	101.93	-
3.	Virtual entry points with an undefined physical location from adjacent gas companies (through the networks of which natural gas of another gas company or group of gas companies can be transmitted)	101.93	-
4.	Points with physical location to/from the Gas Storage Facilities	0.00	0.00
5.	Virtual points with undefined physical location to/from gas storage facility or group of gas storage facilities	0.00	0.00
6.	Virtual points with an undefined physical location to/from the customs warehouse gas storage facility or group of gas storage facilities	0.00	0.00
7.	Exit points with physical location to direct consumers	-	124.16
8.	Exit points with physical location to gas distribution systems	-	124.16
9.	Virtual exit points with an undefined physical location to the gas distribution systems	-	124.16
10.	Virtual exit points with an undefined physical location for operations of the TSO related to the purchase of natural gas by the TSO for its own needs and production and technological costs	-	0.00

3) Depending on the capacity ordering period, the following coefficients apply to the tariffs for natural gas transmission services for internal entry and exit points to/from GTS:

– from March 1, 2020, the coefficient used when ordering capacity for a day in advance - at the level of 1.10 conventional units;
– from April 1, 2020, the coefficient used when ordering capacity for a monthly period - at the level of 1.04 conventional units;
– from October 1, 2020, the coefficient used when ordering capacity for the quarterly period is at the level of 1.02 conventional units.

4) Depending on the capacity ordering period, the following coefficients apply to tariffs for natural gas transmission services for entry and exit points to/from GTS at the interstate connections:

– coefficient used when ordering capacity for a day in advance - at the level of 1.45 conventional units;
– coefficient used when ordering capacity for a monthly period - at the level of 1.2 conventional units;
– coefficient used when ordering capacity for the quarterly period - at the level of 1.1 conventional units, except for ordering capacity for the period of the first quarter of the gas year 2020 - 2021, when the coefficient is applied at level 1.

5) Decreasing coefficients for capacity with restrictions, which are applicable to the tariffs for natural gas transmission services for entry and exit points to/from GTS at the interstate connections:

No.	Point of entry into the GTS of Ukraine/Point of exit from the GTS of Ukraine	Reducing coefficient for a capacity with restrictions, for the point of entry, conventional units	Reducing coefficient for a capacity with restrictions, for the point of exit, conventional units
1	Virtual or physical points (Hermanovichi, Drozdovichi, Ustyluh) at the interstate connection with Poland	0.66	0.49
2	Virtual or physical points (Budince, Uzhhorod/ Velky Kapushany) at the interstate connection with Slovakia	0.66	0.36
3	Virtual or physical points (Berehdarots, Berehove) at the interstate connection with Hungary	0.66	0.44
4	Tekove/Mediash Aurit	0.66	0.41

Calculation of coefficients applied for ordering a capacity within a day

In the instances of non-approval of the coefficient, which takes into account the period of ordering capacity during a day, such coefficient is accepted at the level of 1.1 times higher than the approved coefficient, which takes into account the period of ordering capacity for a day in advance[31]:

- coefficient used when ordering capacity during a day at the entry and exit points to/from the gas transmission system(s) at the interstate connections is equal to 1.595 (1.45 * 1.1).

- coefficient used when ordering capacity during a day for internal entry and exit points to/from the gas transmission system(s) is equal to 1.21 (1.1 * 1.1).

Application of coefficients when booking capacity with restrictions.

In the instances of booking capacity with restrictions, the coefficients that take into account a period of ordering such capacity and the season when such order is made, shall not be applied[32].

Balancing neutrality charge.

Gas transmission services include a balancing neutrality charge, which is determined in proportion to the volume of the Client's gas transmission according to a special formula stipulated by the GTS Code. The rate of balancing neutrality charge may be:

- a positive value (≥0) - in this case the balancing neutrality charge is charged from the Client in favor of the TSO;
- a negative value (<0) - in this case the balancing neutrality charge is paid to the Client.

Daily imbalance fee.

In addition, gas transportation services include a daily imbalance fee[33], which is also calculated for the Client according to a special formula stipulated by the GTS Code. If an amount of daily imbalance is positive (≥0), the payment due for imbalance is made to the Client; if an amount of daily imbalance has a negative value (<0), the fee for imbalance is paid by the Client to the TSO.

[31] In accordance with paragraph 12 of Section VI of the *Methodology for determining and calculating tariffs for natural gas transmission services for entry and exit points on the basis of long-term incentive regulation*, which was approved by Resolution of the Regulator No. 2517, dated 30.09.2015.
[32] In accordance with paragraph 6 of section 10 of Article VI of the *Methodology for determining and calculating tariffs for natural gas transmission services for entry and exit points on the basis of long-term incentive regulation*, which was approved by Resolution of the Regulator No. 2517, dated 30.09.2015.
[33] The difference between the volumes of natural gas supplied by the Client for transmission at the point of entry and those withdrawn by the Client from the GTS at the point of exit, determined according to the allocation.

3.3. Tariffs and expenses related to the gas storage services in the Gas Storage Facilities

The following tariffs and coefficients for services of storage of the Gas Storage Operator should apply[34]:

1) Tariffs for services (excl. of VAT):
- natural gas storage - in the amount of UAH 0.19 (approx. EUR 0.0063) per 1,000 m^3 per day;
- injection of natural gas - in the amount of UAH 110.16 (approx. EUR 3.66) per 1,000 m^3 per day;
- withdrawal of natural gas - in the amount of UAH 63.41 (approx. EUR 2.11) per 1,000 m^3 per day.

2) Coefficients applicable to tariffs for natural gas injection, withdrawal, and storage services:
- coefficient that takes into account the order for individual services of storage, injection, withdrawal of natural gas for a period of one month - at the level of 1.1;
- coefficient, which takes into account the order for individual injection services, natural gas withdrawal per day in advance - at the level of 1.2.

The client ordering natural gas storage (injection, withdrawal) services, to which the annual capacity has been allocated is obliged to make 100% advance payment in the amount of the cost of the booked annual capacity for the period of a gas month, five banking days prior to the commencement of a gas month, in which such service is to be provided.

4. Analysis of customs formalities related to the export of biomethane in accordance with the Customs Code of Ukraine and taxation issues faced by exporters.

Please refer to Section 2 of the Memorandum.

5. Formation of the list of legal issues and potential barriers for the injection of biomethane into natural gas systems, its transmission and further export from Ukraine to the EU, based on legal analysis and comments provided by technical/economic advisers, as well as recommendations for resolving such issues pursuant to the effective laws of Ukraine.

5.1. Definition of the notion “biomethane”

As noted at the beginning of the present Memorandum, the recent amendments to the effective laws of Ukraine introduced the definition of “biomethane” regulating it as a biogas, which in its physical and chemical characteristics corresponds to the regulations on natural gas.

Although the Gas Law, GTS and GDN Codes rather use term “natural gas”, the provisions of the Gas Law shall apply on a non-discriminatory basis to biomethane, if biomethane meets the requirements for access to GTS.

5.2. Units for determining a volume of natural gas

In addition, pursuant to the effective laws of Ukraine, a volume of natural gas is determined in cubic meters, while in the European Union the measurement is made in units of energy (kilowatt-hours).

[34] Pursuant to the Regulator’s Resolution No. 1150 dated 24.06.2020.

Although this does not affect the ability to export and import gas, in practice there may be issues with variations in the recalculation of natural gas at the customs and so on.

In order to eliminate this issue and to ensure transition of the Ukrainian natural gas market to calculations and balancing in units of energy, Ukrainian parliament recently adopted a Draft Law No. 2553, dated 06.12.2019 that sets May 1, 2022 as the date to shift measurement from cubic meters to units of energy. The Draft Law is expected to be signed by the president.

5.3. Issue regarding certification of equipment

There is currently some uncertainty as to whether changes to the equipment certification standards and certain regulations will be required in terms of the possibility of extending such standards and regulations in order to be applied to biogas, biomethane, and other types of gas from alternative sources.

As the Gas Law was amended to extend the term “natural gas” to biogas, biomethane, and other types of gas from alternative sources, it is expected that certification standards and regulations will not require significant changes.

5.4. Draft technical regulation of natural gas

Based on the requirements for natural gas, and, respectively, biomethane, the maximum oxygen molar fraction is 0.02 percent, but almost no technology currently on the market can achieve this level in the process of producing biomethane or it would be extremely expensive. Nevertheless, the adoption of the Technical Regulation of Natural Gas, which is currently being prepared by the Ministry of Energy of Ukraine, should hopefully allow for some flexibility in the parameters of natural gas. The draft regulation provides for a maximum oxygen molar fraction of 0.02 percent (at the points of entry into the network and at the points of interstate connection) or an upper limit of up to 1 percent (if it can be proved that the gas does not enter the installations sensitive to higher oxygen levels, for example, the Underground Gas Storage Facilities) may be applied.

Annexes

Table A1-1 - The list of large cattle farms in Ukraine

№	Farm	Region	Address	Average livestock	Biomethane production potential, m³/hour		Data as of
				heads	Manure only	Manure + 1.5 MS or + 0.66 WS (by raw mass)	
1	LLC "Agrofirm named after Dovzhenka »	Poltava	Yaresky village, Shishatsk district	13 000	186	1 564	2017
2	LLC "Ukrainian Dairy Company"	Kyiv	Velykyi Krupil village, Zguriv district	7 556	108	909	2017
3	Borodino-A	Odesa	Frumushika village, Tarutyn district	7 500	107	902	2010
4	LLC "Agricultural firm"Lighthouse "	Poltava	Kotelva city	7 000	100	842	2019
5	Buchachagrokhlib prom LLC	Ternopil`	Buchach city	6 840	98	823	2014
6	PE "Agroecology"	Poltava	Mikhailiki village, Shishatsk district	6 200	89	746	2017
7	Moloko Vitchyzny LLC	Sumy	Konotop city	6 000	86	722	2019
8	LLC "AE named after Volovikov»	Rivne	Gorbakiv village, Goshcha district	5 520	79	664	2013
9	JSC "Promin`"	Mykolayiv	Arbuzyn district	5 110	73	615	2018
10	LLC "MVK Katerinoslavskyi"	Dnipropetrov sk	Dnipro city	5 000	72	601	2016
11	FG "Veles Vita"	Vinnytsia	Popelyuhy, Druzhba and Bilyany villages, Murovanokurilovets district	4 000	57	481	2020
12	“Ridny Krai” Branch of PJSC Zernoproduct MHP	Khmelnytsky	Novostavtsi village, Teofipil` district	3 700	53	445	2019
13	PAE "Fortuna"	Chernihiv	Yuzhne village, Ichnia district	3 500	50	421	2012
14	PE "Galex-Agro"	Zhytomyr	Strieva village, Novograd-Volynsky district	3 500	50	421	2020
15	LLC "named after Shevchenko”	Cherkasy	Moskalenky village, Chornobayiv district	3 300	47	397	2012
16	Dolynske Trading House LLC	Kherson	Dolynske village, Chaplyn district	3 274	47	394	2019
17	Kishchentsi LLC	Cherkasy	Dobra village, Mankiv district	3 135	45	377	2019
18	PAE "Piskivske"	Chernihiv	Pisky village, Bakhmatsh district	3 040	44	366	2018
19	Nova Nyva LLC	Donetsk	Novokrasnivka village, Nikolsk district	3 000	43	361	2019
20	PE "Lanna-Agro"	Poltava	Lanna village, Karliv district	3 000	43	361	2018
21	STOV "Agroko"	Cherkasy	Chornobayiv district	2 800	40	337	2019

№	Farm	Region	Address	Average livestock	Biomethane production potential, m^3/hour		Data as of
				heads	Manure only	Manure + 1.5 MS or + 0.66 WS (by raw mass)	
22	PSP Agrofirm "Goryn`"	Ternopil	Borsuki village, Lanivtsi district	2 557	37	308	2013
23	PSP "Avanhard"	Chernihiv	Kurin village, Bakhmatsh district	2 535	36	305	2019
24	“Progress” LLC	Volyn	Bilyn village, Volodymyr-Volynsky district	2 500	36	301	2018
25	PAE "Rodina"	Kharkiv	Bogdanivske village, Dvorichansk district	2 500	36	301	2019

Table A1-2 – The largest pig farms (complexes) in Ukraine[1, 2]

№	Farm	Region	Address	Average livestock	Biomethane production potential, m^3/hour		Data as of
				heads	Manure only	Manure + 3 MS (or + 1.33 WS) by raw mass	
1	PJSC "APK-INVEST"	Donetsk	Rivne village, Pokrovsk district	320 485	2 314	18 231	2021
2	JE LLC "Niva Pereyaslavshchyny"	Kyiv	12 pig farms, Pereyaslav-Khmelnytsk district	241 188	1 741	13 720	2021
3	Goodwelly Ukraine LLC	Ivano-Frankivsk	7 farms in Kalush and Galych districts	195 231	1 409	11 106	2021
4	LLC "SPE Globyne pig farm"	Poltava	Globyne district	154 300	1 114	8 778	2021
5	PAE "Agroprod-service"	Ternopil	Nastasiv village, Ternopil district	135 287	977	7 696	2021
6	PJSC "Bakhmut Agrarian Union"	Donetsk	Novoluhanske village, Artemivsk district	90 993	657	5 176	2021
7	PE "Agrarian Company 2004"	Khmelnytskyi	Popivtsi village, Volochysk district	82 830	598	4 712	2021
8	Barkom LLC	Lviv	4 farms in Sambir district, Zolochiv district, Bus`k district and Drohobych district	82 511	596	4 694	2021
9	PJSC "Agroindustrial Company"	Zaporizhzhia	Melitopol district	81 605	589	4 642	2021
11	Chornobaymyaso LLC	Cherkasy	Skorodystyk village, Chornobayiv district	58 760	424	3 343	2021
12	Strong-Invest LLC (KSG Agro Group of Companies)	Dnipropetrovsk	Nyva Trudova village, Apostoliv district	48 926	353	2 783	2021
13	Dan-Pharm Ukraine LLC	Kyiv, Zhytomyr	Khalcha village, Kagarlyk district, village Grozyne, Korosten district	46 221	334	2 629	2021
14	LLC "Zootechnology"	Kherson	Kherson region	44 687	323	2 542	2021
15	Marlen-KD LLC	Kirovograd	Kompaniyivka township, Kompaniyiv district	43 549	314	2 477	2021
16	Agro-Oven	Dnipropetrovsk	Mahdalynivka district	37 000	267	2 105	2021
17	PE "Sigma"	Dnipropetrovsk	Stepove village, Dniprovskyi district	35 830	259	2 038	2021
18	Group of Companies Kolos	Chernivtsi	Chernivtsi region	34 256	247	1 949	2021

[1] http://pigua.info/uk/post/news-of-ukraine-and-world/top-55-najpotuznisih-svinogospodarstv-ukraini
[2] http://pigua.info/uk/post/section/farms-of-ukraine?page=1

№	Farm	Region	Address	Average livestock	Biomethane production potential, m³/hour		Data as of
				heads	Manure only	Manure + 3 MS (or + 1.33 WS) by raw mass	
19	Zolotonis`kyi Bacon LLC	Cherkasy	Medvedivka village, Chyhyryn district	29 106	210	1 656	2021
20	LLC AF "Vil`ne 2002"	Dnipropetrovsk	Vil`ne village, Novomoskovsk district	26 480	191	1 506	2021
21	Agroind LLC	Dnipropetrovsk	Dnipropetrovsk district	24 675	178	1 404	2021
22	Farm "Maks-Agro"	Luhansk	Markivka village, Markivka district	21 600	156	1 229	2021
23	SIMADA LLC	Poltava	Lubny city	21 600	156	1 229	2021
24	LLC "AIC Nastashka "	Kyiv	Nastashka village, Rokytne district	21 090	152	1 200	2021
25	PA "Munnt"	Kirovograd	Verblyuzhka village, Novgorodka district	20 000	144	1 138	2020
26	Eco Meat LLC	Lviv	Batyatychi village, Kamyanka-Bus`ka district	19 711	142	1 121	2021
27	Rosan-Agro LLC	Ivano-Frankivsk	Pidhoroddya village, Dychky village, Rohatyn district	19 500	141	1 109	2021
28	Agroprime Holding LLC	Odesa	Zhovtneve village, Bolhrad district	19 362	140	1 101	2021
29	Steik-Agro LLC	Kyiv	Hlanyshiv village, Pereyaslav-Chmelnytsky district	18 880	136	1 074	2021
30	Uhryniv Eco Farm LLC	Lviv	Sokal` district	17 847	129	1 015	2021
31	Kamchatka LLC	Khmelnytsky	Telizhyntsi village, Izyaslav district	16 207	117	922	2021
32	PE "Agrofirm Svitanok"	Kharkiv	Novoselivka village, Nova Vodolaha	15 768	114	897	2021
33	SE "Danam Farms"	Kyiv	Novosilky village, Kaharlyk district	15 350	111	873	2021
34	Farm "Novy Riven` 2006"	Zakarpattia	Tyachivka village, Tyachiv district	13 053	94	743	2021
35	Vira-1 LLC (Pan Kurchak Agropromgroup)	Volyn	Radoshin village, Drozdni village, Kovel` district	12 879	93	733	2021
36	Cherkasy Meat Company LLC	Cherkasy	Maryanivka village, Lysyansk district	12 706	92	723	2021
37	Chernihiv Meat Company LLC	Chernihiv	Horodyshche village, Mena district	11 953	86	680	2021
38	Pig Breeding Center LLC	Kyiv	Terezyne township, Bila Tserkva district	11 124	80	633	2021
39	Pryluky-Garantbud LLC	Chernihiv	Obychiv village, Pryluky district	10 576	76	602	2021
40	Zhovkivsky PPR LLC	Lviv	Mervychi village, Zhovkva district	10 201	74	580	2021
41	Agrarian LLC "Promin`"	Mykolayiv	Voyevods`ke village, Arbuzynka district	9 992	72	568	2021
42	Lemberg-Agro LLC	Lviv	Hodoriv district	9 346	67	532	2021

№	Farm	Region	Address	Average livestock	Biomethane production potential, m^3/hour		Data as of
				heads	Manure only	Manure + 3 MS (or + 1.33 WS) by raw mass	
43	Krasnopilsky MMK LLC	Sumy	Ryasne village, Krasnopil district	9 200	66	523	2021
44	Servolux-Genetic LLC	Vinnytsia	Rozhychna village, Orativ district	8 500	61	484	2021
45	Artsyzska meat company LLC	Odesa	Dolynivka village, Artsyzsk district	7 902	57	450	2021
46	Agrarian LLC "Ukraina"	Chernihiv	Holinka village, Bahmach district	7 898	57	449	2021
47	Tarutyn Agrarian Company LLC	Odesa	Tarutine village, Tarutine district	6 918	50	394	2021
48	Lvivs`ki Svynky LLC	Lviv	Zhyrova village, Zhydachiv district	6 600	48	375	2021
49	LLC AIC "Dubovyi Gai"	Zhytomyr	Dubovyi Gai village, Ovruch district	6 500	47	370	2021

Table A1-3 – The largest poultries in Ukraine

№	Farm	Region	Address	Average livestock	Biomethane production potential, m^3/hour		Data as of
				heads	Manure only	Manure + 1.5 MS or + 0.66 WS (by raw mass)	
1	Vinnitsa poultry farm LLC	3 departments near Ladyzhyn town	Vinnytsya	39 710 000	15 777	39 032	2021
2	Agro-industrial group of companies "Dniprovska "	5 farms in Dnipropetrovsk and Zaporizhzhia regions	Zaporizhzhia	33 300 000	13 230	32 732	2020
3	Agromars	Gavrylivka village, Vyshhorod district	Kyiv	18 100 000	7 191	17 791	2021
4	LLC "YASENSVIT"	Romashky village, Rokytne district	Kyiv	8 000 000	3 178	7 863	2021
5	PJSC "Volodymyr-Volynsky poultry farm"	11 departments, Fedorivka village, Volodymyr-Volynsky district	Volyn	4 200 000	1 669	4 128	2018
6	Staryn poultry farm of MHP	Myrne village, Boryspil district	Kyiv	3 000 000	1 192	2 949	2020
7	PJSC "Dianovskaya poultry farm"	Kirovske village, Volnovakha district	Donetsk	2 800 000	1 112	2 752	2020
8	Gholubovsky poultry farm of Agro-oven corporation	Novomoskovsk district	Dnipropetrovsk	2 300 000	914	2 261	2021
9	Gubyn poultry farm of AIG "Pan Kurchak"	Gubyn village, Volodymyr-Volynsky district	Volyn	1 850 000	735	1 818	2018
10	Snyatyn poultry farm	Snyatyn town, Kolomyia district	Ivano-Frankivsk	1 350 000	536	1 327	2020
11	Molodizhny poultry farm of Agro-oven corporation	Solonyany district	Dnipropetrovsk	918 000	365	902	2021
12	Morozivka-Agro	3 farms in Balakliya district	Kharkiv	844 000	335	830	2020
13	Avis Poultry Factory branch of PJSC Avanhard	Kosivshchyna village	Sumy	750 000	298	737	2020
14	LLC "Poultry farm Podillya"	Stepanivka village, Vinnytsya district	Vinnytsya	720 000	286	708	2020

Table A1-4 – The largest sugar mills in Ukraine[3]

№	Sugar mill	Region	Address	Production capacity, tons per day sugar beet	Biomethane production potential, m^3/hour
1	PJSC "Food Company" Podillya "(PJSC" Kryzhopil Sugar Plant ")	Vinnytsya	Horodivka village, Kryzhopil district	8000	1 868
2	Radekhiv Sugar LLC (Radekhiv Production)	Lviv	Pavliv. Radekhiv district	8000	1 868
3	Radekhiv Sugar LLC (Chortkiv Production)	Ternopil	Zavodske village, Chortkiv	8000	1 868
4	PJSC "Teofiopol Sugar Plant"	Khmelnytskyi	Theophipil, Khmelnytsky region	7000	1 635
5	Radekhiv Sugar LLC (Khorostkiv Production)	Ternopil	Khorostkiv, Husiatyn district	7000	1 635
6	PJSC "Salivonivka Sugar Plant"	Kyiv	Hrebinky village, Vasylkiv district	6800	1 588
7	PJSC "Gorokhiv Sugar Plant"	Volyn	Maryanivka township, Gorokhiv district	6200	1 448
8	LLC "Novoorzhitsky Sugar Plant" (OJSC "Orzhitsky Sugar Plant")	Poltava	Novoorzhytske township, Orzhytsky district	6000	1 401
9	Tsukorogrocom LLC of Globinsky Sugar Plant (ASTARTA)	Poltava	Globyne	6000	1 401
10	Narkevytsky Sugar Plant LLC	Khmelnytskyi	Narkevichi township, Volochysk district	5900	1 378
11	LLC "Food Company" Zorya Podillya "(OJSC" Gaisinsky Sugar Plant ")	Vinnytsya	Haisyn	5000	1 168
12	Ukrainian Sugar Company LLC (Ed & F Man Ukraine) (Zasilsky Sugar Plant)	Mykolayiv	Pervomaiske village, Vitovsky district	5000	1 168
13	PJSC "Gnidavsky Sugar Plant"	Volyn	Lutsk	4900	1 144
14	Tsukoragroprom LLC. Yareskiv Sugar Plant (ASTARTA)	Poltava	Yareski village, Shishatsky district	4500	1 051
15	Novomyrhorod Sugar LLC (Kapitanivsky Sugar Plant)	Kirovohrad	Kapitanivka township, Novomyrhorod district.	4300	1 004

[3] http://ukrsugar.com/

Table A1-5 – The largest sunflower oil extraction mills in Ukraine[4]

№	Mill	Region	Address	Production capacity, tons per year sunflower oil	Biomethane production potential, m^3/hour
1	KIROVOHRADOLIYA OPEN JOINT STOCK COMPANY	KIROVOHRAD	KIROVOHRAD, KIROVSKY DISTRICT, STREET YIELD, 30	178 500	4 466
2	DNIPROPE-TROVSKY OIL EX-TRACTION PLANT WITH FOREIGN INVESTMENTS CLOSED JOINT STOCK COMPANY	DNIPROPETROV SK	DNIPROPETROVSK, KIROVSKY DISTRICT, LENINGRADSKA STREET, 46	169 705	4 246
3	LLC "KOMBINAT KARGIL"	DONETSK	DONETSK, PETROVSKY DISTRICT, STREET BOITSEVA, 1	154 746	3 872
4	CJSC "POLOGIV OIL EXTRACTION PLANT"	ZAPOROZHYE REGION	ZAPORIZHSKAYA, POLOGIVSKY DISTRICT, POLOGY, STREET LOMONOSOVA, 36	147 021	3 678
5	VOVCHAN OIL EXTRACTION PLANT OPEN JOINT STOCK COMPANY	KHARKIV	VOVCHANSK DISTRICT, VOVCHANSK, PRIVOKZALNA SQUARE, 11	124 650	3 119
6	CJSC "ZAPORIZHZHA OIL FATTY PLANT"	ZAPORIZHZHIA	ZAPORIZHZHA, SHEVCHENKIVSKY DISTRICT, STREET KHARCHOVA, 3	106 994	2 677
7	CJSC "POLTAVA OIL EXTRACTION PLANT - KERNEL GROUP" M. POLTAVA	POLTAVA	36008 POLTAVA, KYIV DISTRICT, STREET MARSHAL BIRYUZOV, 17	106 479	2 664
8	KAKHOV BRANCH OF CJSC "AT KARGILL"	KHERSON	KAKHOVKA, PIVDENNA STREET, 1	101 799	2 547
9	OJSC MYRONIVSKY PLANT FOR PRODUCTION OF CEREALS AND COMPOUND FEED	KIEV	MYRONIVSKY DISTRICT, MYRONIVKA STREET, 1 ELEVATORNA STREET	94 459	2 363
10	CJSC "SLAVIC COLLEGE"	DONETSK	SLOVYANSK, STREET FREEDOMS, 85	74 739	1 870
11	BAT BIHHITSKY OIL-BUT-ZHIBOBY KOMBIHAT	VINNYTSIA	VINNITSA, STAROMISKY DISTRICT, NEMYRIVSKE HIGHWAY, 26	72 969	1 826
12	CLOSED JOINT STOCK COMPANY "PRYKOLO TYANSKY OIL EXT RACTION PLANT"	KHARKIV	VELIKOBURLUTSKY DISTRICT, PRIKOLOTNE TOWN, STREET LENINA, 45	71 626	1 792
13	PERESICHAN OIL EXTRACTION PLANT LIMITED LIABILITY COMPANY.	KHARKIV	61022 KHARKIV, DZERZHYNSKY DISTRICT, STREET SUMY, BUILDING, 47	68 468	1 713

[4] Proagro data

№	Mill	Region	Address	Production capacity, tons per year sunflower oil	Biomethane production potential, m^3/hour
14	ODESSA OIL EXTRACTION PLANT LIMITED LIABILITY COMPANY	ODESSA	ODESA, PRIMORSKY DISTRICT, BUL. SEREDNOFONTANSKA, 16	65 823	1 647
15	ILLICHIV OIL EXTRACTION PLANT CLOSED JOINT STOCK COMPANY	ODESSA	ILLICHIVSK, VUL.TRANSPORTNA, 7-A	40 590	1 016
16	CHERNIVTSI OIL AND FAT PLANT OPEN JOINT STOCK COMPANY	CHERNIVTSI	CHERNIVTSI, SADGIRSKY DISTRICT, STREET MORISA TORESA, 17	35 172	880
17	SWATIVSKA OLIYA CLOSED JOINT STOCK COMPANY	LUHANSK	SVATIVSKY DISTRICT, SVATOVE, PROV. ZAVODSKY, 13	30 624	766
18	ECOTRANS LIMITED LIABILITY COMPANY	MYKOLAIV	54015 MYKOLAIV, ZAVODSKY DISTRICT, 2A ROBOCHA STREET, KV.302	30 110	753
19	UKRAINIAN BLACK SEA INDUSTRY LLC	ODESSA	ILLICHIVSK, STREET TRANSPORT, 44	26 784	670
20	CLOSED JOINT STOCK COMPANY "MILOVSKY REFINED OIL PLANT" STRILETSKY STEP "	LUHANSK	MILOVSKY DISTRICT, TOWN OF MILOVE, PROV.ZAVODSKY, 3	26 630	666
21	OJSC "MELITOPOL OIL EXTRACTION PLANT"	ZAPOROZHYE	ZAPORIZHSKAYA, MELITOPOL, STREET FRUNZE, 31	24 539	614
22	CLOSED JOINT STOCK COMPANY "CREATIVE"	KIROVOHRAD	KIROVOGRAD, KIROVSKY DISTRICT, AVENUE, INDUSTRIAL, 19	23 938	599
23	CLOSED JOINT STOCK COMPANY TRINITY OIL PRESS PLANT	LUHANSK	TROYTSKY DISTRICT, TROYTSKE TOWN, STREET SOVIET, 33	20 318	508
24	BIOIL UNIVERSAL UKRAINE LIMITED LIABILITY COMPANY	ODESSA	ROZDILNYANSKY DISTRICT, ROZDILNA, STREET LENINA, 83	12 190	305

Table A1-6 – The largest distilleries in Ukraine[5]

№	Distillery	Region	Address	Production capacity, ths dekaliters per year	Biomethane production potential, m^3/hour
1	MARYLIVKA DISTILLERY	TERNOPIL	NAGIRYANKA, CHORTKIV DISTRICT	2092.40	826
2	HEMIRIVSKY DISTILLERY	VINNYTSIA	NEMIRIVSKY DISTRICT, NEMYRIV, STREET GHORKOGHO, 31	1831.30	723
3	STATE ENTERPRISE "ZALUCHAN DISTILLERY "	IVANO-FRANKIVSK	SNYATYNSKY DISTRICT, VILLAGE OF DOLISHNI ZALUCHCHIA	1418.00	560
4	KOZLIV DISTILLERY	TERNOPIL	KOZLIVSKY DISTRICT, TOWN OF KOZLIV, STREET ZAVODSKA, 34	1117.10	441
5	NOVOSILKA DISTILLERY	TERNOPIL	PIDVOLOCHYSK DISTRICT, NOVOSILKA VILLAGE	1094.90	432
6	SE "CHERVONOSLOBIDSKY DISTILLERY "	KIEV	MAKARIV DISTRICT, CHERVONA SLOBODA VILLAGE, ZAVODSKA STREET, 1	988.20	390
7	ZALIZTSI DISTILLERY	TERNOPIL	ZBORIVSKY DISTRICT, ZALIZTSI TOWN, STREET BRODIVSKA, 3	917.10	362
8	STATE ENTERPRISE "KOSARSKY DISTILLERY "	CHERKASY	KAMYANSKY DISTRICT, KOSARI VILLAGE	874.90	345
9	STATE ENTERPRISE DOVZHOTSKY DISTILLERY	KHMELNYTSKY	KAMYANETS-PODILSKY DISTRICT, DOVZHOK VILLAGE, STREET UNYAVKA, 1	807.00	318

[5] Proagro data

Table A7 – The largest breweries in Ukraine[6]

№	Brewery	Region	Address	Production capacity, ths dekaliters per year	Biomethane production potential, m^3/hour
1	CJSC PIBZABOD "OBOLON"	KYIV	Kyiv, OBOLONSKY DISTRICT, STREET BOGATYRSKA, 3	110 546	1 850
2	KHARKIV BRANCH OF SANINBEV UKRAINE OPEN JOINT STOCK COMPANY	KHARKIV	61172 KHARKIV. ORDZHONIKIDZE DISTRICT, STREET ROHANSKA, BUILDING 161	48 191	807
3	OJSC "BEER-NON-ALCOHOLIC PLANT" SLAVUTYCH "	ZAPORIZHZHIA	ZAPORIZHZHYA, KHORTYTSKY DISTRICT, STREET G. SAPOZHNIKOVA, 6	34 398	576
4	CHERNIGIV BRANCH OF OJSC "SANINBEV UKRAINE"	CHERNIHIV	17037 CHERNIGIV, NOVOZAVODSKY DISTRICT, str. INSTRUMENTALNA, 20	31 003	519
5	MYKOLAIV BRANCH OF SAN INBEV UKRAINE OPEN JOINT STOCK COMPANY	MYKOLAIV	54050 MYKOLAIV, KORABELNY DISTRICT, YANTARNA STREET, 320	30 056	503
6	BRANCH OF OJSC "BEER-NON-ALCOHOLIC PLANT" SLAVUTYCH "	KYIV	Kyiv, HOLOSIIVSKY DISTRICT, STREET CHERVONOPRAPORNA, 135	21 161	354

[6] Proagro data

Annex 2-1

Location of sites of compressor stations most suitable for connection of biomethane plant

Sumy region (total capacity 296 MWel):

1) CS Sumy-1 and GRS Zagirske:186 MWel; Location: 50°57'35.3"N 34°43'14.8"E
2) CS Romnenky and GRS Severynivka: 110 MWel; Location: 51°02'17.1"N 34°37'47.4"E

Kharkiv region (total capacity 223 MWel):

1) CS Kupiansk-1. 12.5 MWel; Location: 49°44'34.9"N 37°35'30.2"E
2) CS Kupiansk-2: 38 MWel; 49°45'10.5"N 37°36'48.7"E
3) CS Borova-1 and Borova-2: 136 MWel; Location: 49°26'28.5"N 37°38'31.6"E
4) CS Shebelynka-2: 36 MWel; Location: 49°24'02.4"N 36°34'49.8"E

Central region (180 MWel):

1) CS Zadniprovska and GRS Pavlivka : 80 MWel; Location: 48°58'07.9"N 33°13'53.4"E
2) CS Mashivka: 100 MWel and GRS Konovalivka; Location: 49°16'29.1"N 34°48'58.5"E

Northern region:

1) CS Sofiivska and GRS Palmyra: 75 MWel, Location: 49°47'32.0"N 32°06'49.0"E

Annex 2-2

Location of underground gas storages

PSG name	Region	Main infrastructure location, technical point of connection, entrance point of PSG
Ugerske (XIV-XV)	L'viv	49°21'35.2"N 23°54'14.6"E
Bilche-Volytsko-Ugerske	L'viv	49°23'39.2"N 23°42'16.6"E
Dashavske	L'viv	49°17'07.0"N 24°01'31.6"E
Oparske	L'viv	49°23'38.7"N 23°42'15.1"E
Bohorodchanske	Ivano-Frankivsk	48°49'02.1"N 24°29'49.0"E
Olyshivske	Chernihiv	51°13'26.1"N 31°21'46.6"E
Mrynske	Chernihiv	51°03'30.6"N 31°35'44.8"E
Solokhivske	Poltava	49°55'54.4"N 34°35'07.5"E
Proletarske	Dnipropetrovsk	49°00'10.6"N 35°09'22.3"E
Kehychyvske	Kharkiv	49°20'25.9"N 35°49'12.1"E
Krasnopopivske	Luhansk	49°06'23.3"N 38°09'32.0"E
Vergunske*	Luhansk	48°37'16.2"N 39°19'38.1"E

* - temporary occupied territory of Luhansk region

Annex 2-3

Selected gas distribution stations (GRS) and gas distribution substations (GRP/SHRP) most suitable for connection of biomethane plant for all regions of Ukraine

Vynnytsa region

The main and the only operator of gas distribution system in the region is "Vynnytsagas" JSC, is the part of Regional Gas Company (RGK) holding. The company operates averagely 14 000 km of gas distribution networks of Vynnytsa region. Company operated 11 independent routes ("local bushes") of gas transportation (gas of same quality from gas distribution stations to the gasified individual consumers in population centers).

Designed (technical or maximum flow) installed capacity of the whole gas distribution system of Vynnytsagas is 5.9 million nm3/hour, designed distribution installed capacity for 1 Apr 2021 is 2.1 million nm3/hour[1].

Real-life (operating) distributed capacity carried out by distribution system of Vynnytsagas[2]:

2018: 782 million nm3/year

2019: 684 million nm3/year

2020: 619 million nm3/year

The main gas consumer is population (470 million nm3/year or 60% of total distribution). Industrial consumers consume 165 million nm3/year or 21%, heat supply companies – 129 million nm3/year (16%), other (budget, religious organizations) – 2.5%.

The distribution of gas is non-uniform during the year with maximum in winter season (Oct-March) and minimum in summer season, which is connected mainly with the various heating demand.

Monthly gas distribution for 2020 year (million nm3 of natural gas)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	2020 Total
91	81	61	35	23	12	14	15	18	51	101	111	618,6

Average load factor of distribution system and distribution points for latest 3 years is 0.03-0.04.

[1] https://vn.dsoua.com/ua/for-clients/potuzhnosti-grp/id/najavni-velichini-potuzhnostej-grp-stanom-na-1-lip-42759
[2] https://vn.dsoua.com/ua/informacija-pro-kompaniju/informacija-dlja-akcioneriv/actual-info/id/planovi-obsjagi-prirodnogo-gazu-jaki-peremischujut-42557

According to plan of reconstruction till 2030[3], additionally 7-10 million of annual designed capacity will be decommissioned (circling of networks, aggregation of capacities for far underloaded distribution stations to one single station), which does not affect much on the load factor.

The most loaded distribution stations (GRP/SHRP) with the largest currently available flow capacity (consumption) out of total designed capacity (low (0.05 bar) and average (0.05-3 bar) pressure category) suitable for connection of additional capacity to the “local bush” network are the following:

GRP/ SHPR/ GRS ID#	Physical location	Designed installed capacity, ths. nm3/hour	Distributed installed capacity, ths. nm3/hour	Distributed factual minimal annual capacity, million nm3/year	Distributed factual minimal monthly capacity, ths. nm3/month
1010014	Vynnytsya city	50	35.1	11.5	212.0
1010031	Vynnytsya city	50	35.3	11.0	218
1010038	Vynnytsya city	50	35.0	11.2	211.4
1010039	Vynnytsya city	50	35.0	11.1	211.5
1010046	Vynnytsya city	50	35.0	11.0	211.6
1010052	Vynnytsya city	50	35.1	11.0	212.1
1010056	Vynnytsya city	50	35.5	11.1	190.5
1010057	Vynnytsya city	50	35.0	11.0	211.7
1010061	Vynnytsya city	50	35.1	14.7	353
1010072	Vynnytsya city	50	35.0	11.2	211.6
1010075	Vynnytsya city	50	35.0	11.1	211.5
1020001	Haysyn city	44.5	25.5	9.8	200
1110000	Illintsi village	17	12	4.5	100

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
GRS Nemyriv	18	285
GRS Koziatyn	17	250
GRS Glukhivtsi	10	120

[3] https://vn.dsoua.com/ua/files/37292/1

GRS Lypovets	19.6	185
GRS Vynnytsa East	60	1,400
GRS Vynnytsa North and AGNKS	85	800
GRS Vynnytsa South	40	850
GRS Yarmolyntsi	7.8	150
GRS Bratslav	6.5	100
GRS Haisyn (compressor station site)	21	275
GRS Ladyzhyn (GRP of CHP)	35	500
GRS Bar (2 compressor station sites)	16	217.5
GRS Zhmerynka	24	438
GRS Tulchyn	20	300
GRS Trostianets’	20	330

Mentioned GRPD/SHRP in Vynnytsya city are same type with almost same loads. Bearing in mind average local load factor of the system has the guaranteed average annual consumption of 11 million nm3/year of natural gas. The maximum (peak) distribution could achieve 280 million nm3/year for single GRP/SHRP. Real-life monthly operational peak (winter) estimated as 1.85 million nm3/month (2,500 ths. nm3/hour or 8% from nominal distributed installed capacity). The minimal monthly consumption on mentioned GPR/SHPR are on the level of 211 ths. nm3/months (280 nm3/hour or 1% from nominal). All of the identified GRP/SHRP are installed in the city of Vynnytsa (in private housing sector and industrial areas) and technically suitable for connection.

The TSO operates in the region 4 compressor stations for trunk gas transmission network (Bar (two ones), Ilyntsy, KS-18 Haysyn) and 48 gas distribution stations (serving as entrance points for gas supply to Vynnytsagas)[4].

The most priority connection points are compressor station CS-19 Bar (where additionally the reconstruction has been finished by TSO in 2021[5]) with average free capacity estimated as 250 million nm3/year. As for local GRS, the most priority are root-based ones: GRS Glukhivtsi, GRS Lypovets, GRS Vynnytsa Skhidna, GRS Bratslav, GRS Yarmolyntsi.

No PSG and notable “debit gas installations” identified in the region serving as connection points to the network.

[4] https://tsoua.com/gts-infrastruktura/roztashuvannia-gazoprovodiv-terytorieu-ukrainy/
[5] https://tsoua.com/gts-infrastruktura/nashi-investycii/potochni-proekty/

Chernihiv region

Total gas distribution: million 588 nm3/year(2020)

Designed technical capacity: 46 billion nm3/year

Operating distribution installed capacity: 28 billion nm3/year

Average load factor for distribution system: 0.0216

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
24000001	Chernihiv south	450	429	79	3,200
24000027	Chernihiv south	71.5	64.7	12	363
24000033	Chernihiv north	71.5	64.7	11.9	363
24000042	Chernihiv north	71.5	64.7	11.6	354
24000064	Chernihiv north	71.5	64.7	11.6	354
24000083	Chernihiv north	94	88	16.2	493

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
GRS (GRP) Chernihiv 1 (North)	60	1,800
GRS Chernihiv 2 (South industrial zone[6]) Location: 51°27'07.1"N 31°14'43.6"E	320	10,000
GRS Chernihiv 3 (North) Location: 51°32'11.2"N 31°19'54.5"E	100	3,600
GRS Kotsubynske	9.0	200

[6] South techno-park: Chernihiv CHP, wastewater treatment plant, Khimvolokno Chernihiv, construction materials, polymer industries

Priluky GRP agglomeration (GRS not assigned)	30	800
GRS Bakhmach	16	582
GRS Horodnia	13	185
GRS Nizhyn	50	600
GRS Kozelets’	15	250

Perspective PSG for connection:

Name of PSG	Location	Designed capacity, billion nm3	Inlet pressure (min), bar	Infrastructure for additional pressurizing
Mrynske	51°03'30.6"N 31°35'44.8"E	1.5	45	No
Olyshivske	51°13'26.1"N 31°21'46.6"E	0.31	35	No

No notable “debit gas installations” identified in the region serving as connection points to the network.

<u>Khmelnytskyy region</u>

Total gas distribution: 547 million nm3/year (2020)

Designed technical capacity: 5 billion nm3/year

Operating distribution installed capacity: 3.4 billion nm3/year

Average load factor for distribution system: 0.16

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
22070334	Izyaslav city	13.7	12.3	17.0	418.0
22080395	Kamyanets Podilsky district, Humentsy village	2.1	1.8	2.55	61.2

22080621	Kamyanets Podilsky district, Shutnivtsy village	2.8	2.25	3.18	76.5
22100959	Letychiv city	4.7	3.3	4.70	112.7
22150500	Stara Synyava town	9.0	6.89	7.8	60,4
22150510	Adampil village	3.2	2.9	4.2	180.5
22160514	Teofipol city	1.8	1.6	2.2	74.6
22170729	Kormylcha village	1.85	1.7	2.4	44.1
22000040	Khmelnytskyy city	1.9	1.4	2.03	58.0

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Pasichna	24	560
Starokostyantyniv	40	1,250
Teofipol	11	250
Krasyliv	36	850
Khmelnytskyy 1	150	3,200
Malynychy (Khmelnytsk south industry)	40	800
Shepetivka	27	443
Slavuta	25	410
Kamyanets-Podilskyy (including Podilsky Cement)	130	2,300
Derazhnia	15	163
Dunaivtsi	25	429

No PSG and not able “debit gas installations” identified in the region serving as connection points to the network.

Zhytomyr region

Total gas distribution: 457-508 million nm3/year (2020-2021 (prognosed))

Designed technical capacity: 13.5 billion nm3/year

Operating distribution installed capacity: 10.5 billion nm3/year

Average load factor for distribution system: 0.05

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
06010058	Zhytomyr city (center)	14	13.1	9.5	285
06020004	Chernyakhiv town	9.85	9.81	4.2	280
06030055	Myrne village (Berdychiv district)	14.4	12.9	5.6	344
06030066	Berdychiv city (houdeholds)	14.4	13.5	5.8	220
06200020	Vakulenchuk town	18	16.6	7.8	180

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Korosten	20	1,139
Ovrutsch	10	267
Novohrad-Volynsk	15	400
Berdychiv	90	2,500
Zhytomyr	85	2,300
Popil’nya	35	1,473
Brusyliv	30	1,000
Korostyshchiv	25	750

Kirovohrad region

Total gas distribution: 265-376 million nm3/year (last three years 2019-2021) + 25 million nm3/year direct supply (via derivation of gas transmission lines directly to consumers' GRP/SHRP)

Designed technical capacity: 16.1 billion nm3/year

Operating distribution installed capacity: 2.4 billion nm3/year

Average load factor for distribution system: 0.165

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
ГРП №2	Znamyanka city	8.9	5.7	7.4	473
ГГРП №12	Znamyanka city	8.9	8.3	10.7	354
ГРП №5	Znamyanka city	4.4	2.9	3.8	246
ГГРП №16	Subotsci village	8.9	3.8	4.9	188
ГРП №10	Svitlovods'k city	7.8	5.4	7.5	165
ГГРП №13	Svitlovods'k city	26.2	3.5	4.3	120
ГГРП №12	Svitlovods'k city	26.2	24.0	32.0	0-1,826
ГГРП №14	Svitlovods'k city	26.2	13.0	17.7	0-1,138

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Svitlovods'k (industrial area)	105	4,800
Znamyanka 48°44'32.7"N 32°39'31.5"E	53	1,500
Kropyvnytskyy 1 (north west)	46	1,375
Kropyvnytskyy 2 (south east)	60	2,000
Direct supply Kropyvnytskyy west	20	0-1,000

Direct supply Svitlovods'k	25	0-350

Zakarpattya region

Total gas distribution: 362-374 million nm3/year (last three years 2019-2021)

Designed technical capacity: 11.9 billion nm3/year

Operating distribution installed capacity: 1.4 billion nm3/year

Average load factor for distribution system: 0.264

Region has 5 exit/entry points to/from the EU: Uzhgorod (entry), Beregdarotcs (entry), Berehove (exit), Budintsce (exit), Tekovo (exit).

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
ГРП №7	Bushtyno village ("kholodok")	14.6	4.8	11.1	413
ГРП №10	Tiachyv city	32	7.1	17.5	500
ГРП №5	Uzhgorod city (center)	5.65	3.1	7.22	165
ГРП №6	Uzhgorod city (center)	11.8	2.78	6.44	145
ГРП №7	Uzhgorod city (industrial)	2.84	1.95	4.50	130
-	Uzhgorod city (industrial GRP agglomeration bush)	-	-	17.5	520
ГРП №15, 16	Teresva village	46.6	5.8	13.47	200

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Uhzgorod	85	1,800
Mukachevo	30	780

Hust	30	615
Tjachyv	60	1,700
Vynohradiv (near Tekovo exit)	15	350
Verbovets (near Tekovo exit)	13	263
Berehove	10	286

<u>Rivne region</u>

Total gas distribution: 385-387 million nm3/year (last two years 2020-2021(prognosed)), plus 382-385 million nm3/year direct supply (via derivation of gas transmission lines directly to consumers' GRP/SHRP)

Designed technical capacity: 7.8 billion nm3/year

Operating distribution installed capacity: 3.8 billion nm3/year

Average load factor for distribution system: 0.10

Region has large industrial capacities which directly consume natural gas from the transmission trunk pipeline – mainly Rivneazot, Ltd., Volyn cement Ltd. and others.

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **<u>annual capacity</u>**, million nm3/year	Distributed factual **<u>minimal monthly capacity</u>**, ths. nm3/month
16010002	Rivne city (center and sout-west industrial agglomeration)	14.6	9.49	8.3	126.7
16010003		9.0	4.1	3.62	59.6
16010004		14.0	9.1	8.0	151.5
16010005		14.6	9.49	8.7	107
16010006		15.6	9.49	8.3	113.5
16010007		20	9.1	7.7	121.4

GRS:

GRS name	Distributed factual minimal **<u>annual capacity</u>**, million nm3/year	Distributed factual **<u>minimal</u>** **<u>monthly capacity</u>**, ths. nm3/month

Dubno	28.3	735
Direct supply Dubno north (industry and gas filling stations)	5.5	120
Mlyniv	13	232.2
Circle Zdolbuniv[7] → Kornyn →Rivne[8] →Rivneazot → Tynne→Zdolbuniv	48 + 8 + 174 + 325[9] + 5= 550	15,000
Kostopil’	27	450
Berezne	35	536

Chernivtsi region

Total gas distribution: 243-254-304 million nm3/year (2019-2021 (prognosed))

Designed technical capacity: 3.4 billion nm3/year

Operating distribution installed capacity: 2.5 billion nm3/year

Average load factor for distribution system: 0.12

Region has entry/exit point Oleksiivka (Moldavian border)

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
ГРП 10	Vashkivtsi village	5.7	5.7	6.0	143.4
ГРП 15/2	Luzhany town	5.7	3.9	4.2	86.2
ГРП 2	Sokyryany town	5.7	4.1	4.3	120
ГРП 20/1	Chernivtsi (north industrial area)	42	31.4	37.0	1,250

[7] industrial area Volyn cement, construction materials, sawmills, food industry, other industry
[8] all city consumption including DH and industry
[9] direct supply via trunk pipeline GRS Rivneazot

ГРП 34/1	Chernivtsi (east industrial area)	32.5	24.3	25.0	573.0
ГРП 30	Chernivtsi (Mashzavod central area)	13.8	10.3	12.5	360.2
ГРП 5	Petrychanka village	5.7	4.2	4.0	85.5

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Khotyn	19.2	395
Toporivtsi-2	10.7	217.0
Novoselitsya	15.0	263.0
Chernivtsi (Dubrivka)[10]	98.0	1,500

Ternopil' region

Total gas distribution: for region (excluding Ternopil') – 323-335 million nm3/year (2019-2021 (prognosed)), for Ternopil' city only – 180-188 million nm3/year (2019-2021), total 503-523 million nm3/year.

Designed technical capacity (region and city): 5.3 (region), 1.62 (city), total 6.92 billion nm3/year

Operating distribution installed capacity (region+city): 0.67 (region), 0.86 (city), total 1.53 billion nm3/year

Average load factor for distribution system: 0.48 (region), 0.22 (city)

[10] 20 km north to the city, location: 48°23'00.0"N 25°54'04.7"E

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
254-001	Zalyshchyky town	20.5	2.5	10.84	234.2
244-001	Buchach city	28.7	3.6	15.3	437.4
Main GRP #1	Ternopil city (south-center industrial zone)	35.4	9.9	18.94	525.5
Main GRP #2	Ternopil city	46.1	11.2	21.54	597.0

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly capacity**, ths. nm3/month
Kremenets’	65.0	1,400
Lanivtsi	13.2	259.3
Chortkiv	37.4	770
Terebovlya	17.1	338.7
Zalyshchyky	31.4	636
Berezhany	26.5	400
Borshchiv	21.0	321.2
Buchach	23.0	377.0
Husyatyn (infrastructure and 2 compressor stations on adjacent site)	33	689.0
Zbarazh	22.5	350
Zboriv	20.0	284
Pidvolochysk	18.7	253.8
Ternopil’ (infrastructure and compressor station on adjacent site))	165	2,800
Ostriv	36	713

Ivano-Frankivs’k region

Total gas distribution: 506 million nm3/year (2020), plus 95 million nm3/year direct supply (via derivation of gas transmission lines directly to consumers’ GRP/SHRP).

Designed technical capacity: 35.4 billion nm3/year

Operating distribution installed capacity: 16.7 nm3/year

Average load factor for distribution system: 0.031

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
ГРП-39	Zabolotiv village	40	18.5	5.0	130.0
ГРП 18	Nadvirna town (**industrial zone**)[11]	132	61	60	1,400
ГРП №19, 20, 21, 22	Vygoda-Shevchenkovo	22.5	10.9	17	220

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Kalush 1 (north industrial area)[12]	100	2,200
Kalush 2 (south households area)	20	200
Ivano-Frankivsk cement (**direct supply**)	50	2,500
Dolyna GRS and compressor station	27	362
Bohorodchany (GRS and compressor station	40	1,350

[11] supply to PBS BEU (oil and gas storage) and Naftokhimik Prykarpattya (oil and gas refining)
[12] supply to Kalush industrial park: CHP, Karpat Naftochim, Goodwelly Ukraine, ceramics, textiles, polyethylen factory, pharmaceutics, metalworking, etc.

on one site, PSG connection 5 km nearby) [13]		
Burshtyn (CHP island and city)	45	700
Gorodenka	27.5	327.6
Uhryniv (**Ivano-Frankivsk north supply**)	59	924
Lysets (Ivano-Frankivsk west supply)	20	250
Rohatyn	30	395.4
Rozhnyativ	16	338
Svarychiv	18	275
GRS agglomeration Kolomiya, Pidgajchyky, Hody Dobrovidka, Rakivchyuk	20	260
Tysmennytsa (supply company Tysmennytsagas)	33	350

Perspective PSG for connection:

Name of PSG	Location	Designed capacity, billion nm3	Inlet pressure (min), bar	Infrastructure for additional pressurizing
Bohorodchanske	48°49'02.1"N 24°29'49.0"E	2.3	35	Yes

<u>Kyiv region</u>

Total gas distribution: for region (excluding Kyiv city) – 1.6 billion nm3/year (2020), for Kyiv city only – 2.4-2.8 billion nm3/year (2019-2021), total 4.1-4.4 billion nm3/year.

Designed technical capacity (region and city): 36.5 (region), 74.5 (city), total 111 billion nm3/year

Operating distribution installed capacity (region+city): 9.9 (region), 7.5 (city), total 17.4 billion nm3/year

Average load factor for distribution system: 0.163 (region), 0.373 (city).

GRP/SHRP:

[13] Including 20 million nm3 – direct supply for compressor station and PSG own needs

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
GGRP 2	Kyiv city circle	200	15.8	130.45	9,700
GGRP 3	Kyiv city circle	150	23.5	200.5	16,000
GGRP 6	Kyiv city circle	125	40.5	324	26,000
GGRP 7	Kyiv city circle	120	12.2	150	12,600
GGRP 8	Kyiv city circle	150	24.8	200	16,000
GGRP 10	Kyiv city circle	45	12.3	125.8	10,240
GGRP 11	Kyiv city circle	35	17.7	150	11,650
GGRP Koncha Zaspa	Kyiv city circle	5	1.9	13	1,000
GRDPS 4	Kyiv city circle	10	21	120	9,600
10020027	Bila Tserkva city (north industry)	98.5	7.0	33.5	1,000
10020029	Bila Tserkva city (east industry)	20	2.4	20	450
10020053	Bila Tserkva city (armed forces site)	18.6	2.4	5.5	130
10020044	Trushky town	18.6	2.4	3.7	75
10050012	Brovary city north	3.0	3.0	4.8	160
10050013	Brovary city center	3.0	3.0	4.2	120
10040034	Boryspil city center	3.0	3.0	4.6	130
10040048	Schastlyve village (greenhouses)	3.0	3.0	8.5	200
10040052	Velyka Oleksandrivka v-ge industry zone	3.0	3.0	4.2	125
10040063	Schastlyve village (greenhouses)	3.0	3.0	6.5	170
10040077	Voron’kiv village	3.0	3.0	4.5	125
10040702	Boryspil city south	3.0	3.0	4.2	100
10040704	Boryspil city north	3.0	3.0	4.2	100
10060001	Vasyl’kiv city	15	3.33	5.4	150
10060048	Doslidnytske village	15	3.13	4.8	130

10060080	Danylivka village (Kalynivka)	6.75	5.57	8.0	225
10060087	Bahryn village (Kalynivka)	6.75	5.65	8.2	230
10160009	Kozyn city	7.85	7.7	11.0	250
10160015	Pidhirtsi city	11.65	3.8	5.5	150
10070007	Vyshgorod district, Novi Petrivtsi city	7.9	5.0	7.1	165
10070023	Katyuzhanka town	4.4	3.0	4.0	120
10140013	Makariv east industry zone	41	24.5	35.1	750
10250026	Babyntsi village asphalt factory	8	8	11.5	325
10250029	Babyntsi village center households	18	10.2	14.5	300
10120009	Rzhyshchiv city	6.0	3.8	5.5	125
10120018	Stayki village (Kaharlyk district)	7.1	7.1	10.5	236
10150008	Karapyshy village (Myronivka d-ct)	13.4	13.4	19.0	500
10030000	Boguslav city	32	12.7	18.1	450
10190009	Ostriv village (Rokytne d-ct)	11.0	11.0	15.7	442
10130001	Boyarka city	12	11.1	15.8	490
10130003	Boyarka city	5.6	5.3	7.5	213
10130004	Boyarka city	5.6	5.1	7.2	210
10130005	Boyarka city	12	11.2	16	430
10130056	Vyshneve (Kyivska street) industrial zone	32	28	39.9	1,000
10130071	Sofiivska Borschahivka west	32	32	45	1,100
10130076	Sviatopetrovske village (west Vyshneve industry)	30	20	28.5	750
10130095	Sofiivska Borschahivka west	12	8	11.4	270
10210001	Tarshcha town	24	23.7	33.5	800
10210064	Luka village	4.9	4.6	6.5	180

10210144	Kivshovata village	5	4.8	6.9	200
10210089	Chapaivka village	4.9	4.79	6.85	193
10080000	Volodarka town	70.25	17.4	24.9	700
10050062	Gogoliv village	39.0	-	10	200
10080011	Horodysche-Pustovarivka v-ge sugar plant	50.0	-	25	0-800
10220002	Tetiiv town	9.85	9.5	13.6	300
10220001	Tetiiv town	32	32	45.7	700
10220005	Denykhivka v-ge (Tetiiv district)	7.85	5	7.1	200
10220008	Piatyhory v-ge	7.85	6.2	8.9	250

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
GRS Kyiv circle	2,400-3,000	50,000-75,000
GRS Bahryn-Kalynivka-Vasyl'kiv bush	65	1,000
GRS Kozyn-Obukhiv bush (industrial zone)	175	4,000
GRS Kaharlyk-Rzhyshchiv bush	40	650
GRS Myronivka (industrial zone)	75	1,350
GRS Tetiiv	85	1,600
GRS Volodarka	35	600
GRS Bila Tserkva-Pischane bush	220	5,000
GRS Fastiv-Snitynka-Trylisy bush	200	4,650
GRS Boyarka (compressor station site)	70	750
GRS Klavdievo-Borodyanka-Makariv bush	135	2,750
GRS Katyuzhanka-Dymer bush	43	485
GRS Boryspil'	50	750
GRS Baryshivka-Berezan bush (agro industries zone)	60	900

GRS Yahotyn (compressor station site)	85	1,500
GRS Pereyaslav	30	500
GRS Brovary north (greenhouses)	40	675

Kherson region

Total gas distribution: 318-345 million nm3/year (2019-2021 (prognosed))

Designed technical capacity: 45.4 billion nm3/year

Operating distribution installed capacity: 10.6 billion nm3/year

Average load factor for distribution system: 0.033

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
12006165	Beryslav town	47.0	20.5	5.9	97
10915112	Oleshky	47.2	19.0	5.5	93

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Kherson-2 (north **industrial zone**)[14]	75	1,730
Kherson-1 (east zone)	63	1,600
Tsuruypynsk[15]	45	975

[14] Kherson oil extraction plant premises (infrastructure and consumer), Smart Maritime Group Ltd. (large consumer), wastewater treatment plant, poultry farm Chornobaivka and other agro complex facilities nearby

[15] Nibulon elevation river terminal Hola Prystan (large consumer)

Nova Kakhovka	20	166
Kahkovka (**industrial area**)[16]	35	650

Plant Krymskyy Titan (Location: 46°12'05.9"N 33°39'41.9"E) (Ostchem Holding AG) – potential consumer of up to 100 million nm3/year. Currently the status is unknown, plant is temporary closed/conserved.

Sumy region

Total gas distribution: 530-588-594 million nm3/year (2019-2021 (prognosed))

Designed technical capacity: 11.3 billion nm3/year

Operating distribution installed capacity: 3.78 billion nm3/year

Average load factor for distribution system: 0.157

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly** **capacity**, ths. nm3/month
18050003	Stepanivka town (industrial area[17])	14.8	8.8	20	0-400
18010224	Buryn', Konotop district	8.8	7.9	10.9	220
18040354	Hlukhiv city (industrial area[18])	19.7	14.4	20	586
18050039	Lebedyn city	24.5	8	11.0	323
18040367	Krolevets city (industrial area)[19]	12.7	11.7	16.9	375
18010230	Putyvl city	35	9.4	13.1	344

[16] Kargill sunflower oil extraction plant, logistics, agro companies, farms
[17] Agroterminal, elevation, agrologistics, gas terminal, compressor station and nodes/derivations of transmission lines nearby
[18] Elevtaion, agro complexes, metal working, sawmills
[19] Compound feed plant and other agro industry

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly capacity**, ths. nm3/month
Sumy-2 (**industrial area**[20])	80	3,000
Sumy-1 (**industrial and households**)	95	3,200
Kosovschnyna +Doslidna Stantsiya[21]	12	183
Severynivka (site adjacent to compressor station Romnynska)	10	145
Trostyanet's	50	650
Bilopillya	17	250
Nedryhailiv	45.7	1,390
Shostka-1 (industrial)	57	803
Shostka-2	32	318
Hlukhiv	35	780
Konotop	50	650
Duboviazivka	18	238
Buryn'	26	435
Putyvl'	24	467

Zaporizhzhya region

Total gas distribution: 963-976 million nm3/year (2019-2020), plus up to 50 million nm3 direct supply via individual GRS of industries. Two distribution companies – Zaporizhgas (878) and Melitopolgas (88).

[20] Sumy Khim Prom (chemical industry) and others
[21] Avis Ukraine poultry farm nearby

Designed technical capacity: 39.3 billion nm3/year

Operating distribution installed capacity: 18.0 billion nm3/year

Average load factor for distribution system: 0.051

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly** **capacity**, ths. nm3/month
08100002	Zaporizhya city (industrial zone[22])	200	140	130	7,500
08100036	Zaporizhya city (industrial zone[23])	403.2	241.9	145	9,235
08100048	Zaporizhya city (household zone)	88.5	53.1	22.8	526
08100058	Zaporizhya city (south industrial-household zone)	50	31	13.3	450
08100072	Zaporizhya city (center)	100	63.1	30	703
08100051	Zaporizhya city (west industry[24])	25	18	9.8	530
08100053	Zaporizhya city (east industry[25])	193	125.8	54.0	3,000
08100068	Zaporizhya city (south-industrial Communar)	389	237	101	2,700
ГГРП-1	Melitopol city	107	0.76	3.6	170
ГГРП-2	Melitopol city (west industry)	67.2	0.71	6.4	280

GRS:

[22] Ferroaloy plant, coke-chemical factory, Zaporizhstahl, Zaporizh carbon, other heavy industrial complexes
[23] Motor Sich, asphalt industry, food industry
[24] Transformer plant
[25] Asphalt and construction materials plant, Abrasive materials plant, sunflower oil extraction, metalworking, etc.

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Zaporizhzhya-1 (north industrial zone) 47°54'43.3"N 35°15'05.5"E	230	10,000
Zaporizhzhya-2 (west industrial zone)	115	4,500
Zaporizhzhya-3 (south industrial zone)	200	12,000
Kantserivka (west Zaporizhzhya)	25	710
Melitopol’	97	1,500
Tokmak-Molochansk	10	250
Kamianka-Dniprovska (Dniprorudne)	12	300
Dniprorudne (Kamianka Dniprovska[26])	8	0-300
Vil’nyansk	16	350
Pology	20	430
Berdyans’k	60	1,800

Mykolaiv region

Total gas distribution: 380-421-465 million nm3/year (2019-2021(prognosed)), plus ca. 510-530 million nm3/year direct supply (via derivation of gas transmission lines directly to consumers’ GRP/SHRP)

Designed technical capacity: 15 billion nm3/year

Operating distribution installed capacity: 7.3 billion nm3/year

Average load factor for distribution system: 0.059

Region has large industrial capacities which directly consume natural gas from the transmission trunk pipeline – mainly Mykolaiv aluminium plant and south port terminals in Dnipro delta (Korabelniy district).

[26] Nibulon elevation terminal, agro complexes, food industry

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
15900103	Mykolaiv city (south industry, Korabelniy)	82.4	58.1	60.5	935
15900156	Mykolaiv city (south industry, Korabelniy)	40	27.8	14.5	260
15900112	Mykolaiv west	20	13.8	7.1	129
15900137	Mykolaiv north	27.5	19.1	9.7	158
15900183	Mykolaiv city (east industry)	15.0	10.7	16.6	486
15700101	Ochakiv city	26	18.37	9.33	177
15400102	Voznesensk city	38	18.1	18.6	400
15800101	Pervomajsk city	30	20.6	10.5	180
15800102	Pervomajsk city	70	20.6	15.6	314
15400101	Voznesensk city	38	27	13.7	250

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Mykolaiv-1 (**south industrial area**)	130	2,500
Mykolaiv-2 (north household area)	53	750
Mykolaiv aluminum plant	350	10,000
Ochakiv south	13.5	250
Pervomajsk	32	500
Voznesensk north (**compressor station Pivdennobuzka**)	23	453
Voznesensk south (city)	35	450

Cherkasy region

Total gas distribution: 1,372-1,480-1,606 million nm3/year (2019-2021(prognosed)).

Designed technical capacity: 19.1 billion nm3/year

Operating distribution installed capacity: 8.9 billion nm3/year

Average load factor for distribution system: 0.168

Region has large industrial capacities which consume natural gas via GRP/SHRP distribution lines, mainly – Cherkasy azot (Ostchem), Cherkasy CHP, metal production, Smila CHP, construction materials plants and agro complexes in southern-western zone (Shpola, Vatutine, Zvenyhorodka, Katerynopil', Uman').

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
1	Cherkasy center 1	60.6	48.5	60.5	1,500
5	Cherkasy center 2	9.9	6.9	10.1	200
130	Vatutino city	18.4	9.2	10.4	350
156	Helmiyaziv town	37.5	20.6	8.8	150
160	Pischane town	37.5	25.5	10.0	170
166	Palmyra town (compressor station site)[27]	37.5	23.6	13.9	233
277	Smila city	33.4	19.0	20.2	250

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month

[27] Location: 49°47'31.7"N 32°06'48.9"E

Cherkasy-2 (industry south and city) (Location: 49°22'58.0"N 32°00'38.3"E)	800 (350 – GRP of city, 450 – GRP of industries)	20,000
Smila	95	1,791
Zolotonosha	64	1,200
Katerynopil’	7.8	135
Tal’ne (compressor station adjacent site Location: 48°51'07.5"N 30°44'06.6"E)	25	450
Shpola	12	246
Lebedyn	10	243
Uman’	55	600
Khrystynivka	13	120
Monastyrysche	20	378
Starosillya (Horodysche district)	25	270

Odesa region

Total gas distribution: 1,091-1,475-1,377 million nm3/year (2019-2021(prognosed)).

Designed technical capacity: 76.1 billion nm3/year

Operating distribution installed capacity: 74.1 billion nm3/year

Average load factor for distribution system: 0.0184

Region has 4 exit/entry points to/from the EU: Kauschany (transit-entry), Hrebinky (transit-exit) Orlovka (exit), Ananiiv (exit).

No detailed data on GRP/SHRP available

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly capacity**, ths. nm3/month
Odesa port plant Vizyrka	250	12,000

(port Yuzhne)		
Odesa 1 (west)	120	2,000
Odesa 2 (industrial north-east)	230	8,000
Odesa 3 (south)	155	3,500
Chernomorsk	75	1,500
Shustov	30	400
Bolgrad	35	520
Vynohradivka	15	200
Berezivka (compressor station site)	25	230
Rozdil'na	30	350
Ananiiv	20	473

Volyn region

Total gas distribution: 388-395 million nm3/year (2020-2021(prognosed)).

Designed technical capacity: 12.5 billion nm3/year

Operating distribution installed capacity: 3.4 billion nm3/year

Average load factor for distribution system: 0.115

Region has 1 exit/entry point to/from the Belarus – Kobryn-1 (north).

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
02060006	Lutsk city south industrial zone	15	9.7	18.7	280
02060027	Lutsk west (near waste water plant)	11.5	5.6	9.8	172
02060032	Lutsk north industrial zone	7.4	4.0	7.5	150
02060080	Torchyn town	11.0	6.0	12.7	175
02020024	Tsehiv village (sugar plant)	2.8	2.6	7.5	106

02080107	Stara Vyzhivka village	5.2	2.8	5.0	90
02070475	Ivanychy village (sugar plant)	1.22	0.89	7.0	100
02070668	Blahodatne town	4.7	3.7	5.2	108

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly** **capacity**, ths. nm3/month
Lutsk-1	90	2,500
Prylutske (north industrial Lutsk zone)	18	250
Kovel’ (adjacent to compressor station)	30	300
Ivanychy	10	175
Ratne	23	280
Novovolynsk	15	160
Volodymyr-Volynsky	16.4	293
Gorokhiv	20	280

Kharkiv region

Total gas distribution: for region (excluding Kharkiv) – 635 million nm3/year (2020), for Kharkiv city only – 1,493 million nm3/year (2019-2020-2021 (prognosed)), total 2,128 million nm3/year.

Designed technical capacity (region and city): 36.2 (region), 8.3 (city), total 44.5 billion nm3/year

Operating distribution installed capacity (region+city): 7.9 (region), 2.45 (city), total 10.35 billion nm3/year

Average load factor for distribution system: 0.148 (region), 0.68 (city)

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly** **capacity**, ths. nm3/month

-	GRP of Kharkiv MSW plant (south industry)	21.5	8.7	45	2,000
-	GRP Keramzit (east industry, Industrial district)	13	2.7	16.8	600
Mizury Ltd. 821	Kharkiv east	13	3.2	19.5	700
2232 SHRP	Balakliya city	7	4.68	7.5	164
2095	Korobochkyne village, Chuhuiv district (industrial zone)	12	9.5	18.3	515
1733	Pokotylivka village (Kharkiv west)	32	12	15.6	350
8	Derhachy city	28.2	16.3	19.1	400

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Kharkiv-1 (Bezludivka) 49°52'31.6"N 36°18'58.5"E	350	13,000
Kharkiv-2 (Pytomnyk) 50°09'52.4"N 36°15'26.3"E	250	10,000
Kharkiv-3 (Rohan) 49°53'35.8"N 36°28'10.4"E	450	20,000
Kharkiv-4 (Babayi) 49°52'45.3"N 36°11'00.3"E	150	4,500
Derhachy	22	450
CHP-5 Kharkiv	300	12,000
Chuhuiv CHP (Eskhar)	100	0-5,000
Zmiiv CHP (Slobozhanske)	50	0-2,000
Lozova	65	1,200
Barvinkove	18	250
Izyum	46	1,000
Kupjansk-1 (compressor station adjacent site)	60	1,500
Kupjansk-2	48	1,300

GRS Pervomajsk (compressor station site)	30	535
GRS Zmiiv (city)	35	400
GRS Chuhuiv city	37	500

Shebelynka gas production and preparation plant (Location: 49°33'12.9"N 36°37'48.5"E), gas inlet to trunk transmission system 350-400 million nm3/year, Yuliivskiy gas production and preparation plant (Location: 49°59'19.6"N 35°42'36.1"E), capacity 200-250 million nm3/year, Sukhyny gas preparation station and GRS (ca. 50-75 million nm3/year) (Location: 50°03'32.6"N 35°37'55.5"E) with infrastructure for biomethane connection, preparation and pressurizing.

Up to 57 gas extraction, preparation and purification points, gas collection points, boosting compressor stations (up to 100) at Shebelynka and Guty-Kovjagy gas and oil extraction site with total capacity of 7….8 billion nm3/year[28].

Perspective PSG for connection:

Name of PSG	Location	Designed capacity, billion nm3	Inlet pressure (min), bar	Infrastructure for additional pressurizing
Kehychyvske	49°20'25.9"N 35°49'12.1"E	0.7	40	No

<u>Poltava region</u>

Total gas distribution: for region (three gas supply companies) – 588 million nm3/year (2018-2020) for Poltavagas, JSC, 608 (2018-2020) for Kremenchukgas JSC, 103 million nm3/year (2018-2020) for Lubnygas JSC, total average for 2018-2020: 1.3 billion nm3/year. At least 55 million nm3/year is supplied directly via individual GRP of enterprises (mainly Kremenchuk oil & gas refinery, Poltavsky GOK (Horyshny Plavni and others)).

Designed technical capacity (total): 49.8 billion nm3/year (40 billion - Poltavagas)

Operating distribution installed capacity (total): 25 billion nm3/year (20 billion - Poltavagas)

Average load factor for distribution system (total for 3 gas companies): 0.28 (0.03 - Poltavagas)

[28] https://ugv.com.ua/uk/page/gazopromislove-upravlinna-sebelinkagazvidobuvanna

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
GRP 153	Poltava west industry zone	107	101	43.6	1,135
GRP 082	Poltava south industry zone	67.2	67.2	23	400
-	GRP Pishchane (compressor station site)	3.1	1.7	12.5	200
GRP-26	Kremenchuk east	5	2.1	16.5	300
GRP-7	Kremenchuk west	1.8	1.0	8.4	160
-	Veremiivka village (industrial zone Semenivka)	3.1	1.44	5.5	150

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Poltava-1 (west-north industrial zone, Suprunivka)	200	5,000
Poltava-2 (west)	350	8,000
AGNKS Poltava South	30	750
Dykanka (compressor station site)	18	223.8
Myrhorod	40	435
Romodan	25	245
Lubny-1 (north Lubny)	65	1,000
Voinykha (south Lubny)	22	350
Pisky (site of compressor station Lubny)	30	300
Pyriatyn	55	1,250
Hrebinka	25	500
Kremenchuk west (compressor station site)	150	4,250
Potoky	35	483.9

Kryukiv (Kremenchuk south)	50	1,700
Horyshny Plavni (Poltavsky GOK)	180	0-7,000
Kremechnuk oil & gas refinery (direct supply)	50	0-3,250

GPU "Poltavagasvydobuvannya" (Location: 49°56'14.1"N 34°35'47.4"E), gas inlet to trunk transmission system 200-250 million nm3/year with infrastructure for biomethane connection, preparation and pressurizing.

Up to 43 gas extraction, preparation and purification points, gas collection points, boosting compressor stations (up to 61) at Shebelynka-Poltava site) gas and oil extraction site with total capacity of 5….7 billion nm3/year[29].

Perspective PSG for connection:

Name of PSG	Location	Designed capacity, billion nm3	Inlet pressure (min), bar	Infrastructure for additional pressurizing
Solokhivske	49°55'54.4"N 34°35'07.5"E	1.3	40	No

<u>L'viv region</u>

Total gas distribution: 1,342-1,178-1,199-1,072 million nm3/year (2018-2021(prognosed)).

Designed technical capacity: 26.5 billion nm3/year

Operating distribution installed capacity: 9.4 billion nm3/year

Average load factor for distribution system: 0.130

Region has 2 exit/entry point to/from the EU (Poland) – Drozdovychy (entrance), Hermanovychy (exit).

At least 60 million nm3/year is supplied directly to the enterprises (Mykolaiv cement and others).

[29] https://ugv.com.ua/uk/page/gazopromislove-upravlinna-poltavagazvidobuvanna

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
14310002	Boryslav city	9.55	4.5	5.2	180
14310003	Boryslav city	9.55	5.9	6.2	200
14400057	Pidberiztsi village	12.4	4.9	5.66	169
14400119	Velykyi Polokhiv village	5.8	4.5	5.2	140
14500043	Rudky town	5.9	5.0	5.7	175

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Dobrotvir CHP	90	1,000
Chervonohrad	23.1	265
Kamianka Buzska	25	350
Bibrka (compressor station site)	19.4	258
GRS Dobrotvir (Dobrotvir CHP)	65	0-1,000
Drohobych	34	480
Truskavets’	40	530
Dashava	15	175
Zhydachiv	22	225
Mykolaiv (Ustiya)	25	400
Mykolaiv direct supply cement plant	50	0-2,400
Vynnyky (L’viv east)	480	5,000
Sknyliv local bush (L’viv west)	30	350
Novy Rozdil	34	520
Nezhukhiv + Puckenychy (Stryi)	46	394
Sambir	28.3	318

GRS Komarno (CS site)	8	110

Up to 41 gas extraction, preparation and purification points, gas collection points, boosting compressor stations (up to 69) at Drohobych-Boryslav-Rybnyk-Dashava-Mykolaiv site) gas and oil extraction site with total capacity of 0.7….0.9 billion nm3/year[30].

Perspective PSG for connection:

Name of PSG	Location	Designed capacity, billion nm3	Inlet pressure (min), bar	Infrastructure for additional pressurizing
Ugerske (XIV-XV)	49°21'35.2"N 23°54'14.6"E	1.900	40	Yes
Bilche-Volytsko-Ugerske	49°23'39.2"N 23°42'16.6"E	17.050	40	Yes
Dashavske	49°17'07.0"N 24°01'31.6"E	2.150	40	No
Oparske	49°23'38.7"N 23°42'15.1"E	1.920	40	No

Dnipropetrovs’k region

Total gas distribution: for region (excluding Dnipro city) – 1,62 billion nm3/year (2020), for Dnipro city only – 800 million nm3/year (2020), total 2,42 million nm3/year + ca. 1 billion supplied directly to industrial enterprises.

Designed technical capacity (region and city): 59.2 (region), 2.55 (city), total 61.75 billion nm3/year

Operating distribution installed capacity (region+city): 18.9 (region), 2.45 (city), total 21.35 billion nm3/year

Average load factor for distribution system: 0.085 (region), 0.318 (city).

The regions has the most concentrated gas-consumption industrial facility over all Ukraine, the largest consumers are: PJSC Dniproazot, PJSC Dnipro metallurgic plant (Kamyanske), Dnipro metallurgic plant (Dnipro city), PJSC Dnipro tube plant (Interpipe), YuzhMash, Dnipro polymer plant, Arcelor Mittal (Kryvoryzhstahl), Tsentralny GZK (Kryvyi Rig), Sev-GZK (Kryvyi Rig), Vilnogirsk GZK, Nikopol ferroalloy plant PJSC, Zhovti Vody mining, etc.

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal** **monthly** **capacity**, ths. nm3/month
04030004	Verkhnyo-dniprovsk town	22.3	8.44	7.5	219

[30] https://ugv.com.ua/uk/page/gazopromislove-upravlinna-poltavagazvidobuvanna

04030031	Verkhnyo-dniprovsk town	33.3	12.6	14.7	500
04030056	Vilnogirsk	33.3	7.4	10	300
04040035	Kamianske city (south industry)	22.7	16.8	20	700
04100016	Viazivok village (north Pavlohrad)	49	18.5	14	200

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
Dnipro-7 (compressor station Krasnopillya) (Dnipro west)	250	6,800
Dnipro-6 (south)	234	5,000
Dnipro-9A (north)	200	4,500
Prydniprovska CHP	250	8,500
Novomoskovsk-2 (west)	125	6,000
Pavlohrad	100	3,500
Synel’nykove	40	1,150
GRS-2 Kamianske (industrial zone east)	158	7,000
GRS-3 Kamianske	100	2,500
GRS-1 VO Azot	300	12,000
Verkhnyodniprovsk	73	1,580
Vilnohirsk	90	1,840
Zhovti Vody	65	1,385
Kryvyi Rih 3 (Sev-GZK)	120	6,500
Kryvyi Rih 2 (north household area)	70	850
Kryvyi Rih 1/1A (Arcelor mittal)	300	0-15,000
Kryvyi Rih 5 (east household area)	86	1,400
Kryvyi Rih 6 (west household area)	110	1,850
Kryvyi Rih 4 (Shyroke city, InGOK)	135	3,900

Nikopol-1	100	2,650
Marhanets	50	1,000

Perspective PSG for connection:

Name of PSG	Location	Designed capacity, billion nm3	Inlet pressure (min), bar	Infrastructure for additional pressurizing
Proletarske	49°00'10.6"N 35°09'22.3"E	1.0	35	No

<u>Donets’k region</u>

Total gas distribution: 1.797 billion nm3/year (2020), including Donetskoblgas – 808 million nm3/year, direct supply to industrial enterprises – 989 million nm3/year.

Designed technical capacity: 24.7 billion nm3/year

Operating distribution installed capacity: 7.73 billion nm3/year

Average load factor for distribution system: 0.104.

The regions has the large industrial consumers of natural gas (which peaking operation is during period April-August): Kramatorsk CHP, Energomashspetsstal, Slovianska CHP, Svitlodarsk (Vuglegirsk) CHP, ceramics, cement, chemical enterprises.

GRP/ SHPR/ ID#	Physical location	Designed installed capacity, ths nm3/hour	Distribution installed capacity, ths. nm3/hour	Distributed factual minimal **<u>annual capacity</u>**, million nm3/year	Distributed factual **<u>minimal</u>** **<u>monthly</u>** **<u>capacity</u>**, ths. nm3/month
GRP№10	Bakhmut city (south)	19	13.1	12	120
GRP№24	Bakhmut city (east-north)	33.3	18.4	20.8	350
GRP№34	Bakhmut city (west-north)	19	13.8	12.6	180
GRP№51	Soledar, Nosova	33.3	5.4	10.0	150
GRP I, II	Kramatorsk Novikova, Khabarovska	64.2	4.2	17.3	300
GRP 10	Kramatorsk, Alfa factory	32.1	29.1	40	0-1,200
GRP #1	Rodynske, Kotovskoho	20.5	12.3	11.4	220

GRS:

GRS name	Distributed factual minimal **annual capacity**, million nm3/year	Distributed factual **minimal monthly capacity**, ths. nm3/month
GRS Pravdynska (Novomykolaivka)	20	200
GRS Shydlivsky KVZ (west Sloviansk)	50	600
GRS Kramatorsk (industrial zone)	320	6,500
GRS Sloviansk	250	5,000
GRS Sloviansk CHP	50	1,500
GRS Druzhkivka	60	450
GRS Kostyantynyvka 1,2	350	8,000 (Sept), max (35,000-45,000) in July-August
GRS Toretsk	40	550 (coal mining zone)
GRS Avdiivka (Avdiivsky coke-chemical plant)	100	1,000
GRS Artemivsk Bakhmut[31]	300	7,000
GRS CHP Svitlodarsk (Vuglegirsk)	70	0-2,900
GRS Pokrovsk [32]	75	1,350
GRS Elektrostahl Kurakhove[33]	265	5,000
GRS-1 Mariupol (Azovstahl, city consumption)	225	5,500
GRS-2 Mariupol (MMK, city consumption)	200	4,200

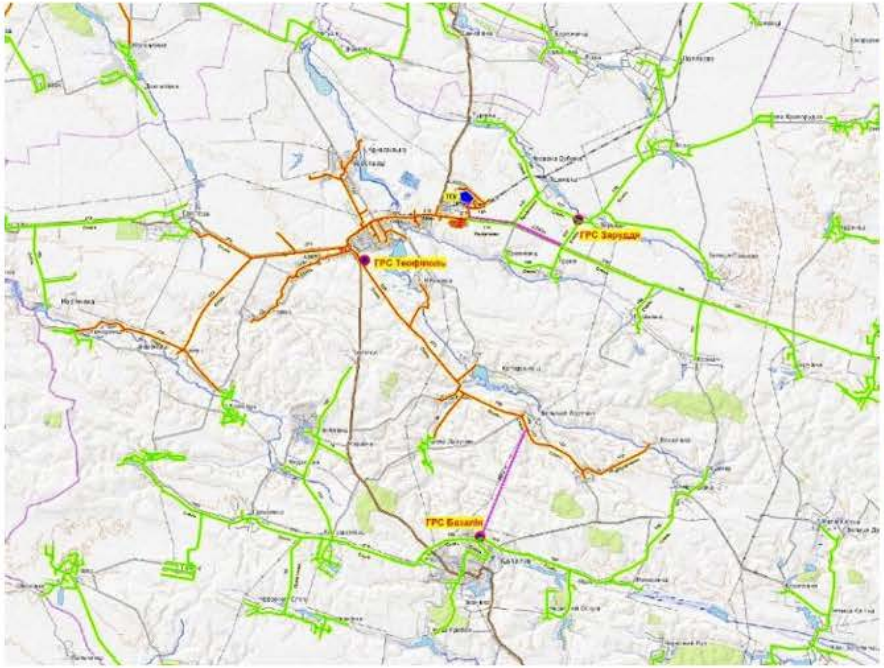
[31] Heavy industrial area: Artemmash, Artem factory of non-ferrous metals, Polymer Spp, AZSHV (champaign factory)
[32] Agro and food industries, CHAO APK Invest, coal mining and coke-chemical industry

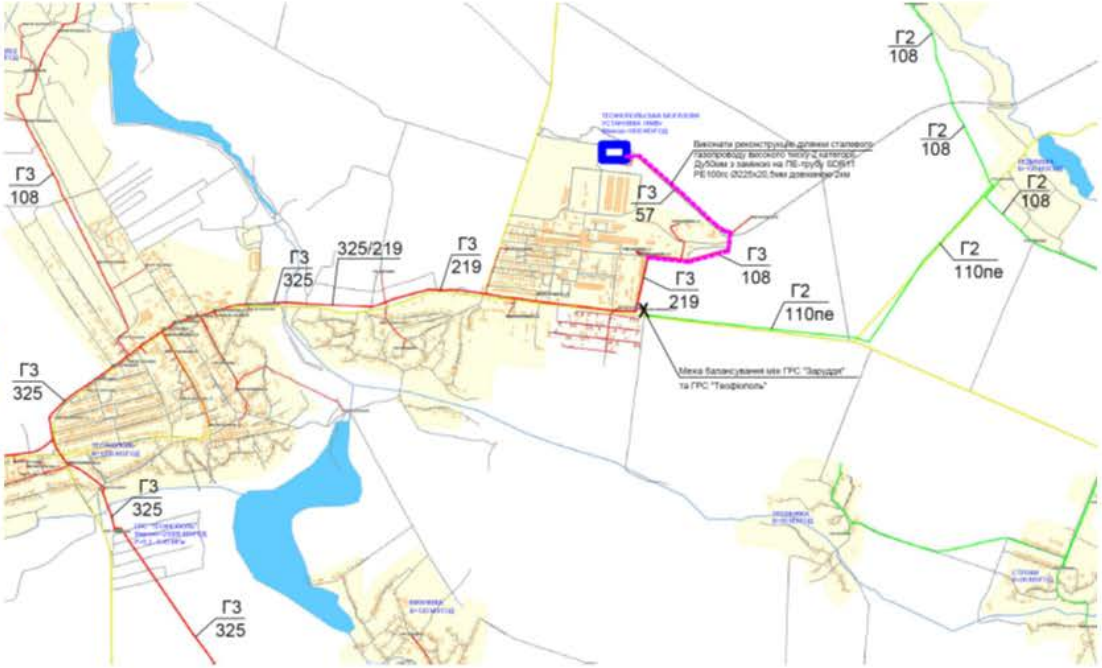
[33] Kurakhiv technopark: SIMZ, Elektrostahl, Kurakhove CHP, metal and oil/gas storage bases

Annex 2-4

Schemes of RGK linked to concrete networks layouts adjacent to existing biogas plants

Teofipol biogas plant connection scheme (Khmelnytskyy region)

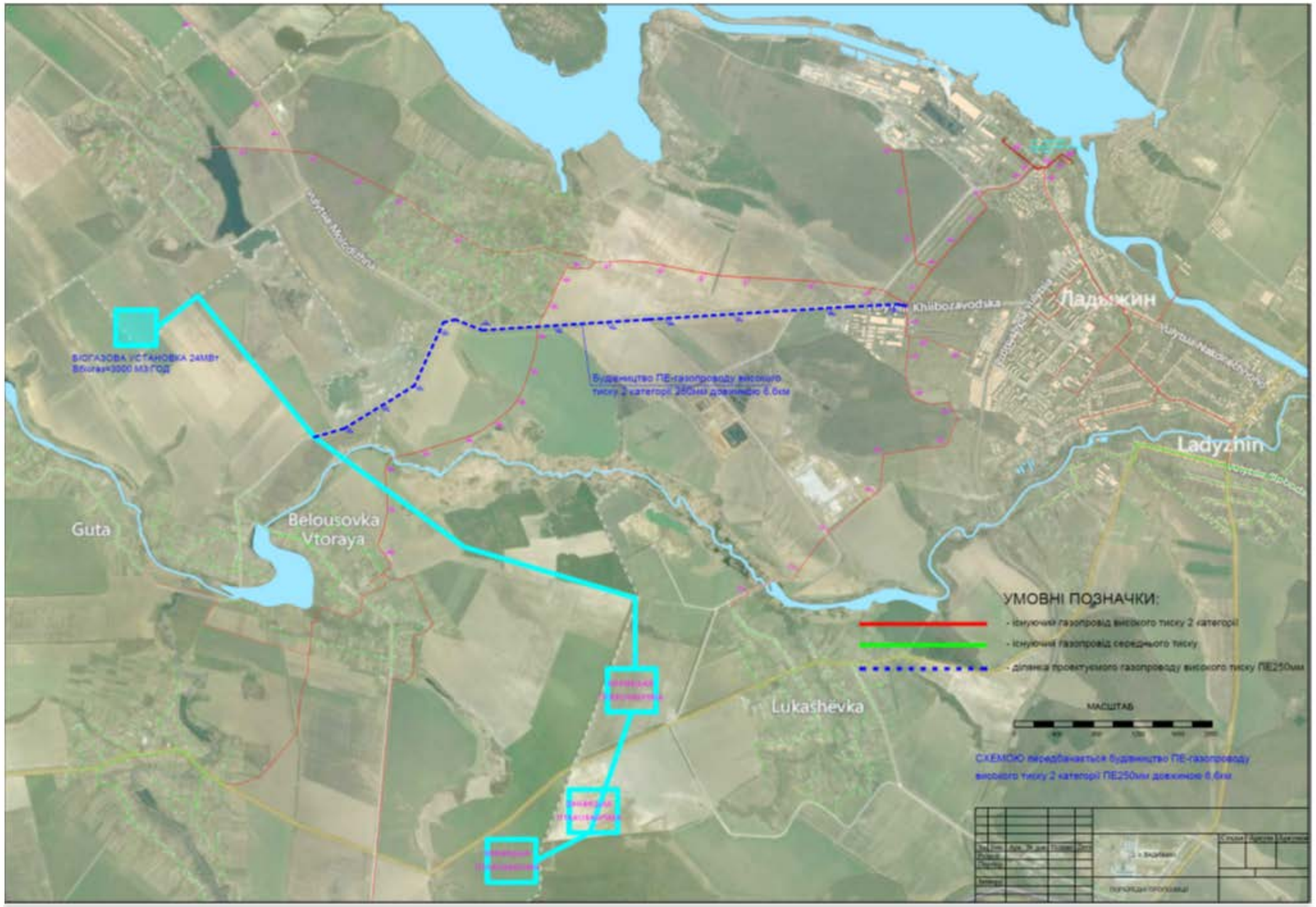




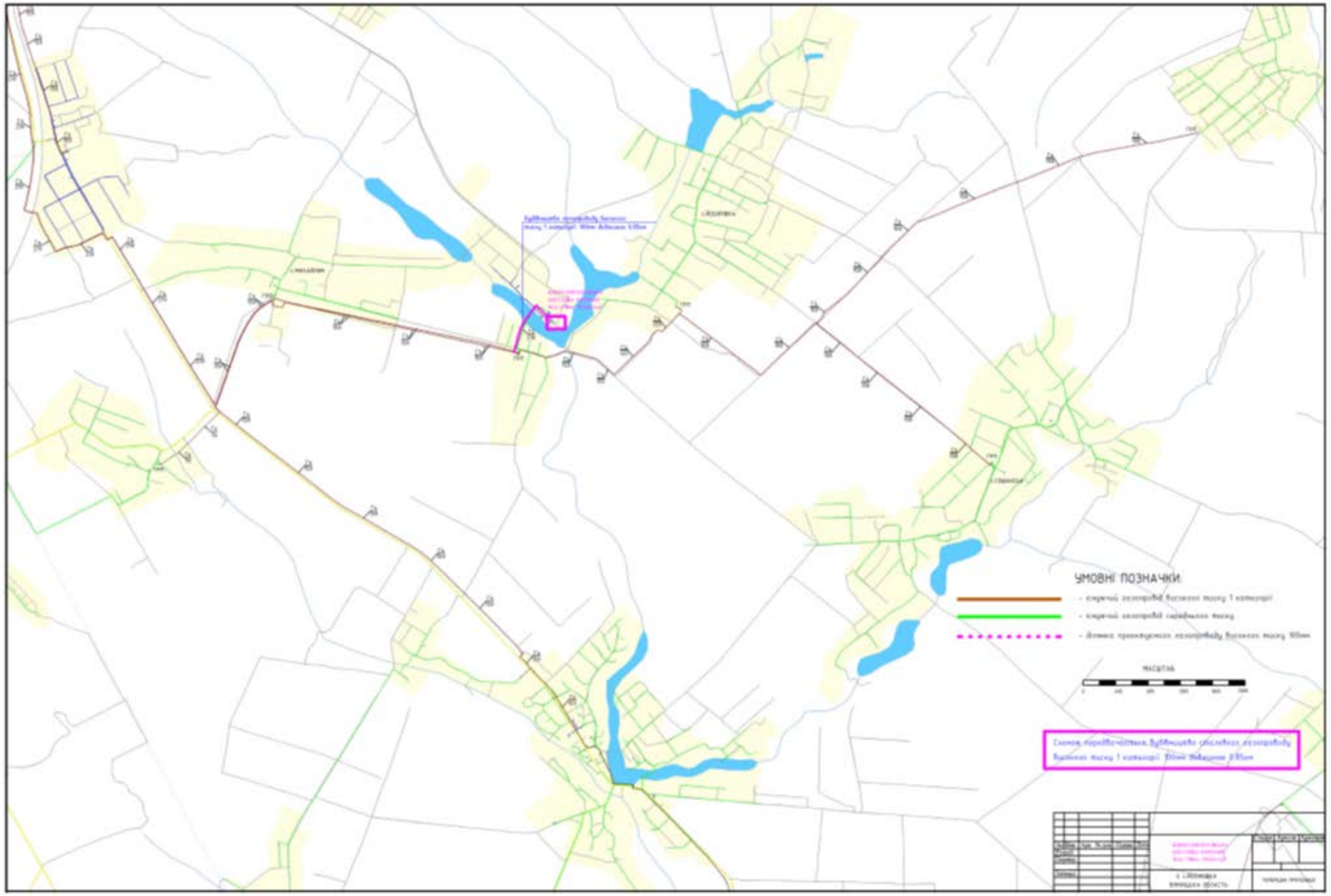
Connection with encircling of two GRS

Connection on balancing border between two GRS (on level of GRPs)

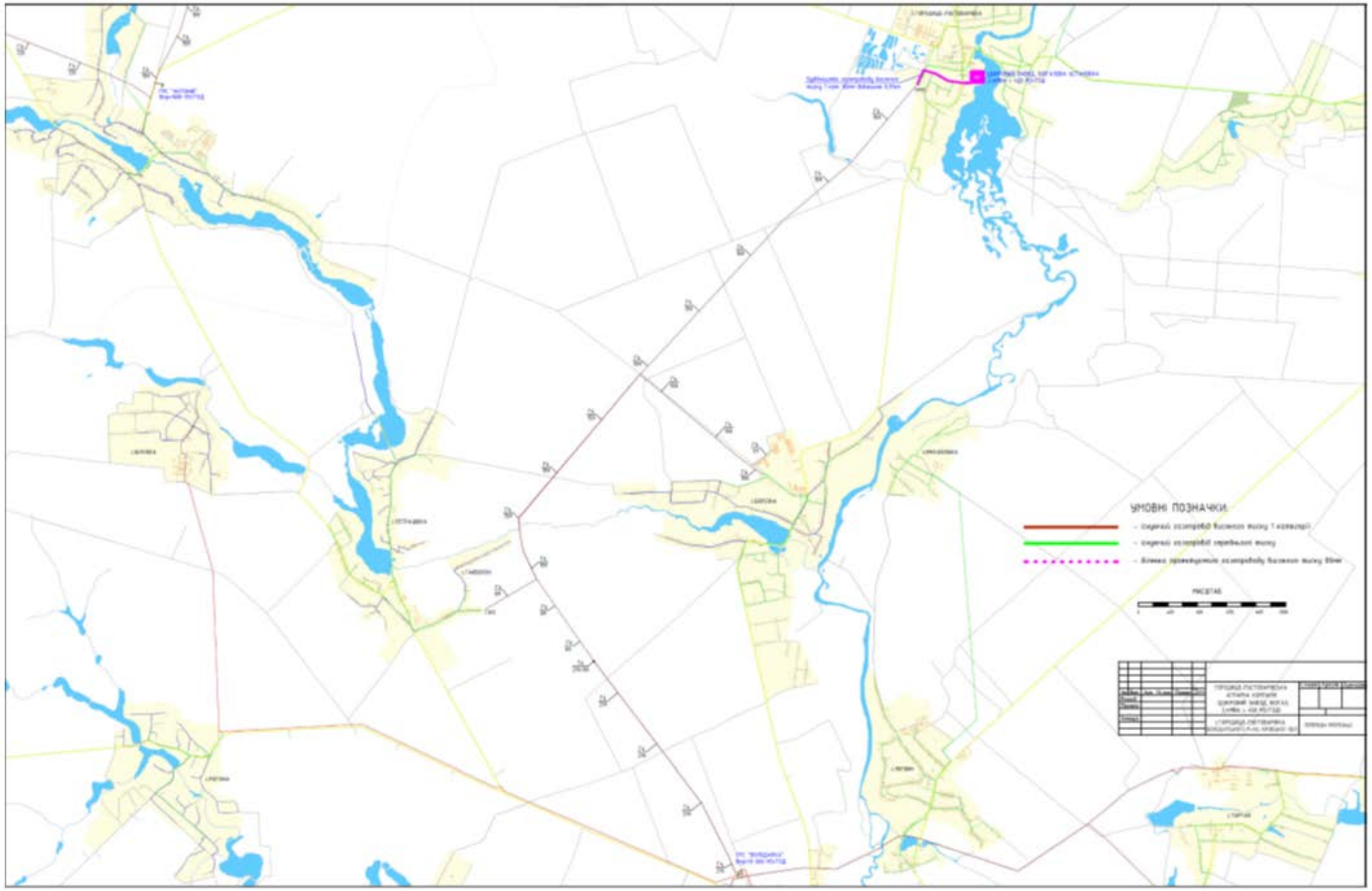
Ladyzhyn biogas plant connection scheme (Vynnytsya region)



Josypivka biogas plant connection scheme (Vynnytsya region)



Horodysche-Pustovarivka biogas plant connection scheme



Annex 4-1

Biomethane projects depreciation table

Initial investment costs	EUR	Depreciation %	Depreciation year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
									DEPRECIATION EUR										
Construction works	2 915 000	4,0%	25	0	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600	116 600
Technological machinery	3 480 000	12,5%	8	0	435 000	435 000	435 000	435 000	435 000	435 000	435 000	435 000							
Measuring and steering system	475 000	12,5%	8	0	59 375	59 375	59 375	59 375	59 375	59 375	59 375	59 375							
CHP unit	450 000	12,5%	8	0	56 250	56 250	56 250	56 250	56 250	56 250	56 250	56 250							
Pipelines	285 000	4,0%	25	0	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400	11 400
Electricity network connection	130 000	8,3%	12	0	10 833	10 833	10 833	10 833	10 833	10 833	10 833	10 833	10 833	10 833	10 833	10 833			
Engineering, inspection	290 000	20,0%	5	0	58 000	58 000	58 000	58 000	58 000										
Loading and harvesting machines	150 000	12,5%	8	0	18 750	18 750	18 750	18 750	18 750	18 750	18 750	18 750	18 750	18 750	18 750	18 750			
Roads	150 000	4,0%	25	0	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000	6 000
Land	100 000																		
Other costs, reserve	300 000	20,0%	5		60 000	60 000	60 000	60 000	60 000										
Total:	**8 725 000**			**0**	**832 208**	**832 208**	**832 208**	**832 208**	**832 208**	**714 208**	**714 208**	**714 208**	**163 583**	**163 583**	**163 583**	**163 583**	**134 000**	**134 000**	**134 000**

Auxiliary investments	EUR			2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
CHP unit year 8	157 500											157 500							
CHP unit year 15	157 500																		157 500
Machinery years 6-8	696 000									232 000	232 000	232 000							
Machinery years 12-15	1 044 000															261 000	261 000	261 000	261 000
Measuring and steering year 5	118 750								118 750										
Measuring and steering year 10	118 750													118 750					
Loading machine year 11	150 000														150 000				
Total	**2 442 500**								**118 750**	**232 000**	**232 000**	**389 500**	**0**	**118 750**	**150 000**	**261 000**	**261 000**	**261 000**	**418 500**

Depreciation - auxiliary investments	EUR	%		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
CHP unit year 8	157 500	12,5%											19 688	19 688	19 688	19 688	19 688	19 688	19 688
CHP unit years 13 - 16	157 500	12,5%																	
Machinery year 6-8	696 000	12,5%									29 000	58 000	87 000	87 000	87 000	87 000	87 000	87 000	87 000
Machinery years 12-15	1 044 000	12,5%															32 625	65 250	97 875
Measuring and steering year 5	118 750	12,5%								14 844	14 844	14 844	14 844	14 844	14 844	14 844	14 844		
Measuring and steering year 10	118 750	12,5%													14 844	14 844	14 844	14 844	14 844
Loading machine year 11	150 000	8,3%														12 450	12 450	12 450	12 450
Total										**14 844**	**43 844**	**72 844**	**121 531**	**121 531**	**136 375**	**148 825**	**181 450**	**199 231**	**231 856**

Depreciation total				2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
From initial investment					832 208	832 208	832 208	832 208	832 208	714 208	714 208	714 208	163 583	163 583	163 583	163 583	134 000	134 000	134 000
From auxiliary investments										14 844	43 844	72 844	121 531	121 531	136 375	148 825	181 450	199 231	231 856
Total					**832 208**	**832 208**	**832 208**	**832 208**	**832 208**	**729 052**	**758 052**	**787 052**	**285 115**	**285 115**	**299 958**	**312 408**	**315 450**	**333 231**	**365 856**

Annex 4-2

Biomethane project cash flow analysis

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Revenue from sales		**2 896 401**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**	**3 218 223**
Raw material costs		1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000	1 330 000
Energy (electricity) costs																	
Personnel costs		60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000	60 000
Maintenance (incl. spare parts)		50 956	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825	203 825
Other material costs		10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
Liquid digestate transportation		91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010	91 010
Other operational costs		26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988	26 988
Fix costs		70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900	70 900
Total direct and indirect costs		**1 639 854**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**	**1 792 723**
EBITDA		**1 256 546**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**	**1 425 500**
Depreciation		832 208	832 208	832 208	832 208	832 208	729 052	758 052	787 052	285 115	285 115	299 958	312 408	315 450	333 231	365 856	365 856
EBIT		424 338	593 292	593 292	593 292	593 292	696 448	667 448	638 448	1 140 385	1 140 385	1 125 542	1 113 092	1 110 050	1 092 269	1 059 644	1 059 644
Interest paid on credit			-427 961	-395 493	-361 076	-324 594	-285 924	-244 933	-201 483	-155 426	-106 605	-54 855					
Amount subject to profit tax		424 338	165 330	197 799	232 216	268 697	410 524	422 515	436 965	984 960	1 033 781	1 070 687	1 113 092	1 110 050	1 092 269	1 059 644	1 059 644
EBITDA		1 256 546	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500	1 425 500
Profit tax		63 651	24 800	29 670	34 832	40 305	61 579	63 377	65 545	147 744	155 067	160 603	166 964	166 508	163 840	158 947	158 947
Operational Cash Flow (interest paid, taxed)		1 192 896	1 400 700	1 395 830	1 390 668	1 385 195	1 363 921	1 362 123	1 359 955	1 277 756	1 270 433	1 264 897	1 258 536	1 258 993	1 261 660	1 266 553	1 266 553
Investment Cash Flow (subsidised)	-8 725 000	0	0	0	0	0	-118 750	-232 000	-232 000	-389 500	0	-118 750	-150 000	-261 000	-261 000	-261 000	-418 500
Op. & Investment Cash Flow	-8 725 000	1 192 896	1 400 700	1 395 830	1 390 668	1 385 195	1 245 171	1 130 123	1 127 955	888 256	1 270 433	1 146 147	1 108 536	997 993	1 000 660	1 005 553	848 053
Financing	6 543 750																
Credit service (repayment + interest)			-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104					
Financing Cash Flow	6 543 750		-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104	-969 104					
Cash Flow	**-2 181 250**	**1 192 896**	**431 597**	**426 726**	**421 564**	**416 092**	**276 068**	**161 019**	**158 852**	**-80 848**	**301 329**	**177 043**	**1 108 536**	**997 993**	**1 000 660**	**1 005 553**	**848 053**