

BIOMETHANE: PRODUCTION, USES AND ENVIRONMENTAL IMPACT

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Abstract

The climate changes of last decades require more and more the finding of alternative solutions for the provision with electrical and thermal energy of at the farm level. The first biomethane plant from biogas was put into operation in Germany in 2006, thus offering an alternative to fossil fuels. Biomethane is used in liquid form as bio-LNG or in gaseous form as bio-CNG. In addition to its use in the electricity and heating markets, biomethane is particularly suitable for freight transport, while bio-CNG is more suitable for passenger cars, delivery vehicles, public transport and tractors. At the same time, at the farm level, biomethane offers a decarbonisation tool by providing electricity and heat with a closed carbon cycle, being a renewable gas that can replace fossil fuels. At present, depending on European and national legislation, each of the European countries has its own means to support the biomethane market. This paper aims to present the current situation of biomethane production technologies, the possibilities of their use at farm level and the impact on the environment.

Key words: biomethane, biogas upgrading, climate change, renewable energy, carbon cycle.

INTRODUCTION

Finding alternative sources to reduce carbon dioxide (CO₂) emissions and other polluting emissions with greenhouse effect was and is a constant and deep concern of farmers but also tractors and agricultural machinery manufacturers (KunakAIR, 2025). It has been known for decades that at the farm and municipal community level, manure, landfills and decomposing organic waste release methane (CH₄), a greenhouse gas 28 times more potent than carbon dioxide (CO₂) (Arnau, 2025a). Therefore, biogas plants collect it through controlled and sealed anaerobic digestion, producing biogas, thus preventing methane (CH₄) from evaporating into the air. According to research in the field, biogas consists of 50-60% methane (CH₄), depending on the nature of the substrate and pH of the reactor. The rest consists of carbon dioxide (CO₂) and minor accompanying gases such as hydrogen sulfide (H₂S), nitrogen (N₂), oxygen (O₂), siloxanes, volatile organic compounds (VOCs), carbon monoxide (CO), and ammonia (NH₃) (Adnan et al., 2019; Angelidaki et al., 2018). The transformation of biogas into biomethane (known as upgraded biogas) involves the separation of these non-combustible gases. After

processing raw biogas, biomethane typically contains only very small amounts of carbon dioxide (CO₂), usually less than 1-5%. While the original biogas still consists of about 30-50% CO₂, this is removed through refining processes to achieve methane (CH₄) content of over 95-99% (Kabeyi & Olanrewaju, 2024).

Although the first biomethane plant from biogas was put into operation in Germany in 2006, upgrading of biogas on an industrial scale in the EU developed a few years later. Founded in 2009 The European Biogas Association (EBA) counts today on a well-established network of over 350 national associations and other organisations covering the whole biogas and biomethane value chain throughout Europe and beyond (EBA, 2020). Another benefit of biomethane production is that after biogas upgrading, carbon capture, utilization, and storage (CCUS) is becoming a very popular decarbonisation solution. This means that the reductions of CO₂ emission into the atmosphere can only be achieved by either reducing the CO₂ emissions from the sources or increasing the usage of CO₂ for another purpose (Adnan et al., 2019). Once purified, CO₂ can be used in numerous industrial fields: carbon fertilization in greenhouses; wastewater treatment; food applications in the brewing and carbonated soft

drinks industry; food applications for remineralization of drinking water or obtaining dry ice that it can be used in both the food and non-food industry (Godoy et al., 2024; Arnau, 2025b).

According to statistics, biomethane production worldwide in 2023 was around 8 billion cubic metres (bcm), from which 4.9 bcm production in the EU, with the majority injected into natural gas grids for use in industry, transport and buildings. The remainder bottled as compressed natural gas (CNG) for use as a transport fuel. As of 2025, Europe has 1,678 biomethane plants in operation with an annual production capacity that has reached 7 bcm (IEA, 2025a). Europe significantly dominates the biomethane market share in the global market and has the most mature biomethane production ecosystem. France, Germany, Italy, United Kingdom, and the Denmark are leading, with Spain that also is in a phase of accelerated growth (Table 1) (Arnau, 2025a). At least 86% of the biomethane plants currently active in Europe are known to be connected to the gas grid. 7% of European biomethane plants do not have a grid connection, and for the remaining 7% of Europe's plants no information is available to the EBA database (European-biomethane-map-2025).

Table 1. Countries with the largest biomethane installed capacities (in Nm³/h - *Normal Cubic Meters/Hour*)

	2025		2024		2022
France	190,711	Germany	147,749	Germany	147,711
Germany	157,258	France	132,818	United Kingdom	107,029
Italy	99,658	United Kingdom	114,358	France	87,691
United Kingdom	93,161	Italy	97,757	Denmark	70,105
Denmark	85,142	Denmark	85,117	Sweden	45,421

(Source: Arnau, 2025a)

Therefore the European Commission fully recognises these benefits and in its recent REPowerEU plan set a target of 35 billion cubic meters (bcm) of annual biomethane production by 2030 (Alberici et al., 2022).

Romania has also a huge potential for developing biomethane production capacities. According to European Commission analyses Romania has ability to replace about 80% of current NG imports with biomethane. However, there is currently no such facility in Romania (Energy Magazine, 2024).

Biomethane provides new opportunities at different levels for the society because compares

to raw biogas, can be used both for energy production and vehicle fuel (Kabeyi et al., 2024; Godoy, 2024).

METHODS AND TECHNIQUES FOR UPGRADING BIOGAS INTO BIOMETHANE

As previously stated, biomethane or upgraded biogas is made by qualitative processing of raw biogas through several steps to remove impurities mainly CO₂, that causes environmental problems such as climate change (Mohammadpoura, 2024). Today, the use of biomethane as a fuel in the transport sector is also very promising, as it can be used in natural gas vehicles without further conversion. Biomethane is very valuable for use in transport sectors, e.g. in liquid form in heavy-duty transport, but also in agriculture sector, so that biomethane can contribute to the successful decarbonisation of these sectors (Figure 1) (Snam, 2025). Bio-Liquefied natural gas (or bio-LNG) is liquefied biomethane, a drop-in replacement for its fossil LNG counterpart. This is not only easily transportable but also guarantees greater efficiency when used as a fuel (Snam, 2025).

This renewable substitute for LNG offers the same advantages that LNG offers over Diesel: reduction of carbon dioxide (CO₂) emissions; quieter engine operation; reduction of nitrogen oxide (NO_x) emissions and significantly fewer emissions of polluting particles (Rehman et al., 2020). The main stages in obtaining biomethane are as follows: *biogas production* (raw material collection, methanization), *biogas purification*, *filtration-odorization* and *pressure regulation*. After these processes, biomethane is ready for the final stage: *reinjection into gas networks* (Alberici et al., 2022). After biogas purification (i.e. removal of residues of CO₂, H₂S, NH₄, water vapor), etc., the methane content increases from 55% to ≥96%. It should be noted that, like natural gas, for safety reasons, when introducing biomethane into the network it is filtered and odorized (Alberici et al., 2022). Figure 2 presents the technologies for obtaining biomethane from different sources of raw materials.

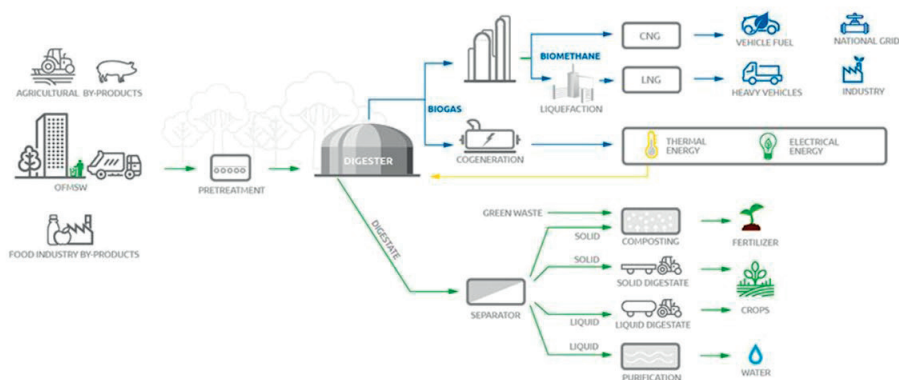
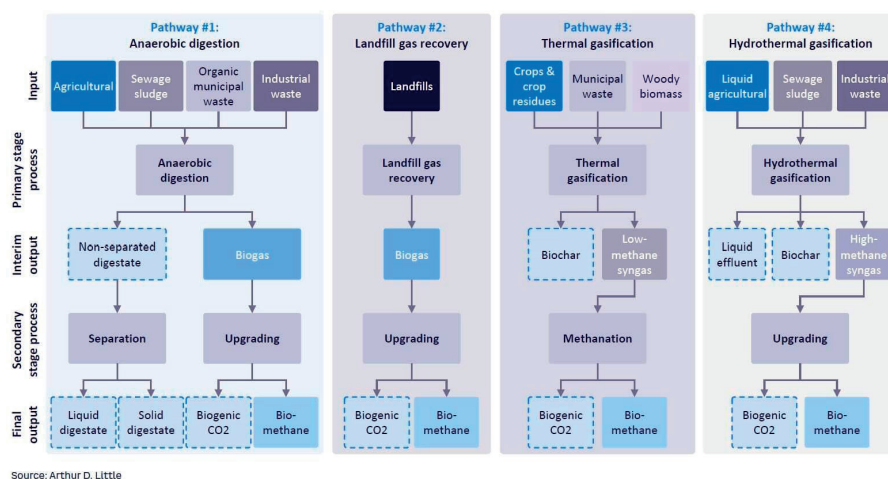


Figure 1. Biomethane production scheme through biogas upgrading
(Source: <https://www.snam.it/en/our-businesses/biomethane.html>)



Source: Arthur D. Little

Figure 2. Biomethane production pathways
(Source: <https://www.adlittle.com/mx-en/insights/viewpoints/future-biomethane>)

In order to eliminate unwanted components from biogas, such as CO_2 and H_2S , and to obtain an efficient fuel thus increasing its specific calorific value, several upgrading technologies have been proposed. All technologies for methane enrichment have in common, that the accompanying gas compounds besides to methane are removed by using physical, biological or chemical applications (Weiland, 2003; Ahrens & Weiland, 2007; Hurtig et al., 2025). Common technologies for *removal of H_2S* are: **biological desulphurisation** and **adsorption with activated carbon or iron and zinc oxide** (Ahrens & Weiland, 2007). For the removal of CO_2 the following strategies are well

known. Figure 3 presents a simplified schema of these currently applied technologies. The gas absorption method is divided into two categories: *physical and chemical purification*. The *adsorption method* is usually carried out in a process called Pressure Swing Adsorption (PSA). For the *CO_2 separation method*, membrane separation technology or cryogenic separation is applied. The cleaning process also captures biogenic CO_2 , which can replace fossil CO_2 in many processes or be removed permanently from the greenhouse gas emission cycle (Directorate-General for Energy, EU 2025).

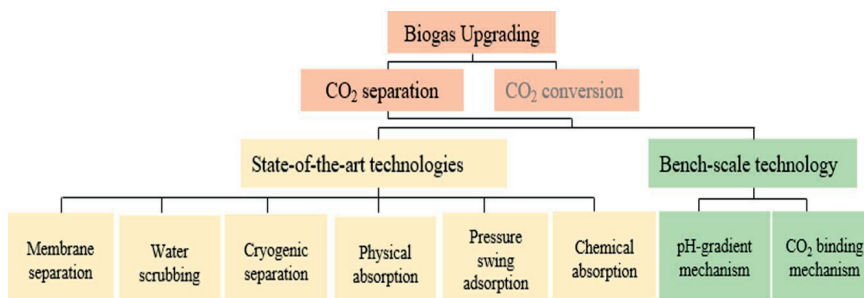


Figure 3. Technologies for biogas upgrading in to biomethan
(Source: Mohammadpoura et al., 2024)

Upgrading technology involves a significant investment and can vary substantially depending on the scale of the facility and the region where the biogas plant is located (IEA, 2025b). The cleaning and upgrading processes commonly represent approximately 20-40% of the total investment costs for a new biogas plant (Ammenberg et al., 2021). Each method of obtaining biomethane by upgrading biogas has a series of advantages and disadvantages. Among these we can list:

- **Water scrubbing**

The water scrubbing process is used to remove carbon dioxide CO₂ and hydrogen sulfide H₂S from the biogas composition, since these gases are more soluble than methane. One of the advantages of this biogas purification process is that no special chemicals are required to remove carbon dioxide CO₂ and hydrogen sulfide H₂S. The disadvantage is that it requires the use of a large amount of water (Zhao et al., 2010).

- **Chemical absorption**

Chemical absorption involves the formation of reversible chemical bonds between the solution and the solvent. Solvent regeneration involves the breaking of these bonds and brings a relatively high energy ratio. The advantages of this process are: complete removal of hydrogen sulfide H₂S, high efficiency and reaction rate compared to wet scrubbing, and the ability to operate at low pressure. The disadvantages are the use of additional chemicals and the need to treat the chemical waste resulting from this process (Zhao et al., 2010).

- **Pressure Swing Adsorption**

Pressure Swing Adsorption (PSA) is a technology used to separate certain types of gases from a mixture under pressure, depending on their molecular characteristics and affinity

for the adsorbent material. The main disadvantages are an additional step of removing hydrogen sulfide H₂S, the need for waste gas treatment, and high costs. The advantages of the pressure swing adsorption process are: reduced emissions, removal of nitrogen N and oxygen O, methane enrichment by over 97% and reduced energy requirements (Zhao et al., 2010).

- **Membrane Separation**

This technique uses polymeric membranes to separate the CO₂ from the methane in biogas while under high pressure (Green, 2018; Ardolino et al., 2021). The membrane separation process produces ultrapure carbon dioxide that can provide an additional source of income for plant operators, and can be subsequently used in a wide range of industries (food industry, horticulture, firefighting or refrigeration plants) (Laumann, 2025).

- **Cryogenic Separation**

Cryogenic separation of biogas is based on the fact that CO₂, H₂S and all other biogas contaminants can be separated from CH₄ based on the fact that each contaminant liquefies at a different temperature-pressure domain (Bauer et al., 2013). This separation process operates at low temperatures, near -100°C, and at high pressures, almost 40 bars. The main advantage of cryogenic separation is the high purity of the upgraded biogas (99% CH₄), as well as the large quantities that can be efficiently processed. The main disadvantage of cryogenic separation is that cryogenic processes require the use of considerable process equipment, mainly compressors, turbines and heat exchangers. The need for the equipment raises capital and operating costs relative to other options (de Hullu et al., 2008; Zhao et al., 2010).

• Amine Scrubbing

Amine scrubbing system uses a two-step approach to upgrading biogas. The first step is adsorption followed by a second step of stripping or desorption. Benefit claims of systems suppliers include: low electricity usage; thermal efficiency; greater than 99.5% CH₄ capture; low usage of water and amine solvents; wet process can minimize need for robust pretreatment; system handles VOCs, siloxanes and H₂S; fully automated to minimize operator attention; flexible system that can easily turn down capacity if needed; CO₂ off-gas is pure enough to recover for subsequent reuse (Green, 2018). Recently, advancements are being made towards new technologies such as *electrochemical CO₂ separation*. (Mohammadpoura et al., 2024).

WAYS TO USE BIOMETHANE

As previously described, in the case of biomethane production, it must be taken into account that, in addition to the methane used as fuel, biomethane plants produce useful, sustainable and indigenous by-products, such as digestate, biogenic CO₂ and biochar. (Directorate-General for Energy, EU 2025).

Usually, 1 m³ of biogas typically yields around 0.56 m³ to 0.62 m³ of biomethane when upgraded (Boglárká (Bogi), 2025). The digestate, or organic residue resulting from anaerobic digestion, is rich in nutrients (phosphorus, nitrogen and potassium) essential raw materials for EU agriculture. If correctly applied in agriculture, this biofertilizer can support sustainable agriculture and generate additional income for biomethane producers. (Directorate-General for Energy, EU 2025).

Purified form of CO₂, the so-called biogenic CO₂, can be captured, stored and used in various applications in other areas of agriculture or the food industry (for example as a process stimulating agent for greenhouse plants, for water treatment or in the food and beverage sector) (Directorate-General for Energy, EU 2025). At the same time, biochar can improve soil health and decompose raw materials, or it can be a terrestrial option for carbon removal because it locks carbon in the soil for the long term (Directorate-General for Energy, EU 2025). Year after year, the establishment of

biomethane stations constitutes a challenge for both industry and farmers due to the increasing demand for biofuels. In the European Union scenario for the years 2030 (Figure 4) and 2050 (Figure 5), one can observe both the trend of increasing the amount of biomethane and changes in the production technology (anaerobic digestion or thermal gasification) for each country.

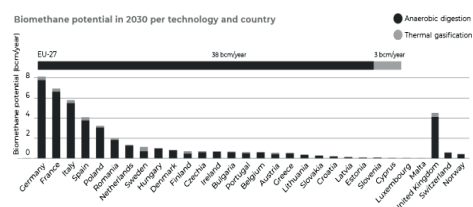


Figure 4. Biomethane potential in 2030 per technology and country (Source: Alberici et al., 2022)

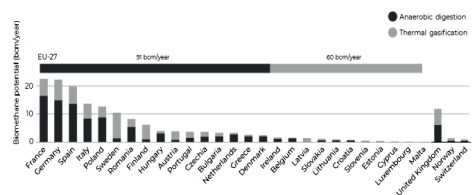


Figure 5. Biomethane potential in 2050 per technology and country (Source: Alberici et al., 2024)

At a global level, especially in the USA and China, the scenarios for 2030 are also optimistic, taking into account the growing demand for renewable natural gas and import activities (Figures 6 and 7). At the present time, at national level, many countries use dedicated support mechanisms for the development of the biogas and biomethane sector, including feed-in tariffs, premium feed-in tariffs and fiscal incentives. Feed-in tariffs are the minimum prices guaranteed, over a defined period, by the national governments for each kWh generated, either injected into a network or directly used (Prussi et al., 2019).

At European level, the gas network is generally structured in 3 layers: *high pressure, medium pressure and low pressure networks*.

Usually the biomethane produced is injected locally into the low pressure network, which is designed for unidirectional flow. This can be a disadvantage because - unlike the electricity network - it depends on local gas consumption

to create space for new inputs (Boglárka (Bogi), 2025). Therefore, in summer, when the demand for biomethane is lower and the gas supply exceeds local consumption, the delivery pressure decreases, which can cause congestion in the network. Therefore, during this period, the ability of producers to inject biomethane constantly is limited, especially in rural areas where there is low demand for gas for heating (Boglárka (Bogi), 2025).

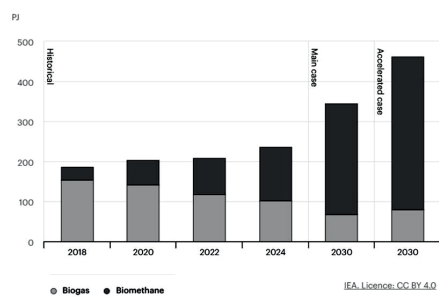


Figure 6. Production of biogas and biomethane in the United States, 2018-2030 in petajoules (PJ) (Source: IEA, 2025b)

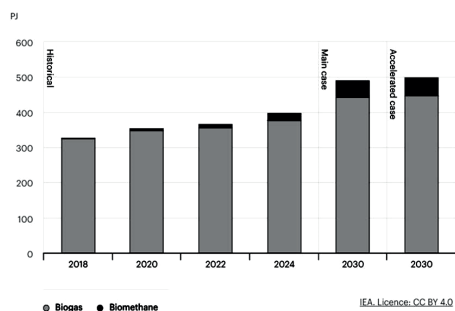


Figure 7. Production of biogas and biomethane in the China, 2018-2030 in petajoules (PJ) (Source: IEA, 2025b)

Biomethane as a vehicle fuels

Biomethane can be used as a green fuel for vehicles, referred to as **bioNGV** (Nagy & Princz-Jakovics, 2025). It produces no nitrogen oxides (NOx), no black smoke, and minimal greenhouse gas emissions and it is available in compressed (bioCNG) or liquefied (bioLNG) forms (<https://www.engie.com>). Vehicles which can be fueled using compressed natural gas, and as a result biomethane, include generally heavy duty vehicles (trucks and city, buses), passenger cars, and for a few years now also tractors.

Approximately 20–30 million vehicles globally are fueled by compressed natural gas or biomethane (Ammenberg et al., 2021). The use of biomethane as a fuel requires a series of costs. The main costs are due to: biogas upgrading, CH₄ liquefaction, distribution, filling station and the costs of vehicles using biomethane. Today, engines designed for methane propulsion are currently being produced by several truck and bus manufacturers, including Daimler (2018), Isuzu (2018), Iveco (2015), Scania (2017) and Volvo Trucks (2017) (Gustafsson & Svensson, 2021). In the Nordic countries, where gas grids are limited (except in Denmark), biomethane is primarily used in transportation (Finland and Sweden) (Boglárka (Bogi), 2025).

Research carried out in various projects has shown that in the case of biomethane used as a fuel for vehicles, the potential for reducing greenhouse gas emissions *depends mainly on the raw material used*. In addition to the fact that a reduction of 60-80% was found compared to gasoline, a greater potential for reducing these emissions was also observed when using organic waste and municipal waste, compared to biomethane obtained from energy crops (IRENA, 2018). This fact thus allows the expansion of biomethane stations in non-agricultural areas where there are large quantities of waste obtained from the retail or wholesale sector (expired food products). Under Central European conditions, it has been calculated that in general the total cost for biomethane production, meaning all stages from raw material supply to injection into the gas network, varies from 0.28 USD/m³ to 1.94 USD/m³ CH₄ (IRENA, 2018). The calorific value of biogas is between 20.7 and 27.8 MJ/m³, while the biomethane calorific value is higher (about 37.7-39.8 MJ/m³). This difference largely affects the respective costs, when used for energy production, ranging between 0.89 and 2.97 pence/kWh for the case of biogas and 1.49-3.30 pence/kWh for biomethane (Gkotsis et al., 2023). To be injected into a vehicle, biomethane must be compressed to at least 200 bars at the refilling station, in order to exceed the pressure in NGV fuel tanks. Vehicles can also be retrofitted for bi-fuel operation, knowing that methane delivers almost the same performance and efficiency as gasoline (IRENA, 2018). With the same levels of power and torque as its diesel

equivalent, farmers also benefit from up to 30% lower running costs. It produces 99% less particulate matter, cuts overall emissions by 80% and when using methane reduces CO₂

emissions by 10-15%. When running on biomethane near-zero CO₂ emissions are achievable (EIP-AGRI Project, 2023).



Figure 8. New Holland T7.270 Methane Power Tractor
(Source: <https://agriculture.newholland.com>)

In the transport sector, the EU has set a target of 14% by 2030 in the use of renewable energy sources. In addition, at least a share of 3.5% of final energy consumption in the transport sector by 2030 will have to come from advanced biofuels, generally defined as fuels derived from waste or non-food biomass, such as animal manure, the organic fraction of municipal solid waste or agricultural by-products (Tratzi et al., 2022). Alternative propulsion technologies in agriculture to reduce pollution and climate change impact are broadly investigated in research, especially electric batteries (for electric tractors) and liquefied gas or compressed gas (for diesel engines) (Gustafsson & Svensson, 2021). The New Holland T6.180 Methane Power is the world's first 100% methane powered production tractor and is key to CO₂ reduction without compromising performance (EIP-AGRI Project, 2023). The new series T7 270 Methane Power CNG tractor can run on biomethane derived from livestock manure, supporting on-farm sustainability (Figure 8).

Refilling can be performed directly from the gas grid network or at specific biomethane stations. Research on methane-powered tractors has shown that they not only have the potential to reduce pollutant emissions by 80%, but also significantly reduce fuel costs. This directly

contributes to a lower carbon footprint. The T7 Methane Power features all-new NEF 6.7L engine specifically developed for agricultural applications by FPT Industrial, a leader in natural gas power train technology (Vale, 2025). This engine model has 6 cylinders with 4 valves and stage V, with 3-way catalyst, 6728 capacity (cm³). The engine's peak torque is 1,160 Nm, and produces a maximum 199 kW (270 hp) and a rated engine speed - 2200 (rpm). The methane tank capacity at 200 bar and 25°C is 656/115 (litres/kg) along with an optional 480-litre range extender and that offers an incredible autonomy of higher than 11 hours at medium duty (Vale, 2025).

Environmental Impact

Through the studies undertaken and published technical reports, Edwards et al. (2014), Börjesson et al. (2016), Gustafsson et al. (2021), note that in addition to the advantage, the climate change impact of biomethane can even become negative if external effects of biogas production are included in the calculations. Thus, regarding the environmental impact, it must be taken into account that if the pollutants removed from biogas (CO₂, H₂S and even residual CH₄) during the upgrading are emitted into the atmosphere, the environmental contamination will be as high as in the case of

using current fossil fuels. Depending on each process used for biogas upgrading, there may be solutions to avoid this inconvenience. For example, in the case of the *chemical absorption method*, a catalyst is usually used. This can be either amines for CO₂ absorption or Fe/EDTA complexes for H₂S absorption. In the case of the *high-pressure water purification method*, especially the CO₂-enriched air is removed and traces of CH₄ are burned. The largest amount of CO₂ and H₂S is absorbed in the stripper during the gas phase. The *pressure swing adsorption method (PSA)* involves burning CH₄ from the residual flow in the heat engine of a generator. Sometimes the waste stream is recycled which leads to an increase in the CH₄ yield in the product stream. The *cryogenic separation process*, as an environmentally friendly technique, does not use chemicals, but consumes considerable energy. Here too the waste stream consisting of a high percentage of CO₂ with traces of H₂S and CH₄ must be treated carefully in order not to be harmful to the environment. In the case of the *membrane separation method*, the waste gas still contains CH₄, which is very polluting. It is recommended that part of this quantity be reintroduced into the intake or, as in pressure swing absorption, the waste gas be burned in a gas engine connected to a generator (Zhao et al., 2010).

Romania case

Unfortunately, at the present time, Romania represents one of the least developed biogas markets in the EU27, but has ability to replace about 80% of current NG imports with biomethane. In the field of road transport as infrastructure, in 2022 Romania has 12 CNG charging stations compared to Italy which has 1063, Germany 868 or Sweden 178 (<https://cngeurope.com/countries/romania/>). This means that, current number CNG filling stations are not sufficient to have a larger uptake of biomethane in transport. Industry estimates Romania’s sustainable biomethane potential as 2.0 bcm (1.9 bcm from anaerobe digestion and 0.1 from gasification) by 2030 (Figure 9 and Table 2). According to reports prepared by the European Commission, considering the sustainable potential, Romania could be among the top biomethane markets in the EU27, with

significant national benefits (BIOMETHANE FICHE - Romania, European Commission -2021). For all that weakness, in 2030 Romania is planning a 5% share of biomethane in its natural gas network and to double it by mid-century. The sectors of waste management and agriculture can produce an estimated 501.000 tons of oil equivalent in 2050 (Todorović, 2025).

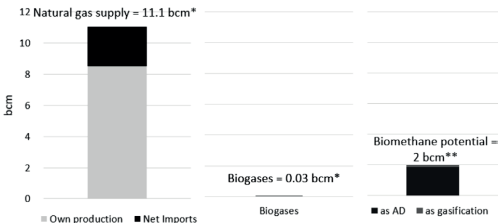


Figure 9. Comparison of current natural gas supply, biomethane production and potential in Romania (Eurostat: Energy Balances, 2022)

Table 2. Biogas/biomethane potential in bcm, by feedstock for Romania (Source: Guidehouse: Gas for Climate Report, 2022)

Feedstock	Production pathways	
	Thermal gasification	Anaerobic Digestion
Wood waste	0.05	-
Forestry residues	0.04	-
Landscape care wood	0.03	-
Municipal solid waste	0.02	-
Agricultural residues	-	0.8
Animal manure	-	0.4
Biowaste	-	0.3
Sewage sludge	-	0.02
Industrial wastewater	-	0.05
Roadside verge grass	-	0.01
Sequential crops	-	0.31

CONCLUSIONS

At the farm level, biogas and biomethane, produced locally from organic materials such as agricultural residues, manure, and sewage sludge, it can both decarbonization and energy security. At the same time, biomethane, produced from organic waste and residues, is a renewable and circular fuel that transforms waste into clean energy - delivering environmental, economic, and social benefits. It is a prime example of the circular economy applied to transport. A tailored national approach is needed in the future to maximise the

value of these resources. Differences between countries in strategic priorities for renewables resource availability and infrastructure need to be taken into account. The researches and studies demonstrated that a biomethane car, truck or tractor is less expensive than other renewable forms of propulsion (for example electric or H₂). The advantage is due first of all to compatibility with natural gas and this means that biomethane has an existing charging/ and vehicle infrastructure. On the other hand the fact that biomethane is nearly climate neutral, producing more than 90% fewer climate emissions. From an economic point of view, the production cost of LBM is much higher than in the case of LNG. This is due to the fact that natural gas has the advantage of that it exists in large volumes and requires relatively cheap processes to obtain a high-energy fuel and upgrading biogas to biomethane is produced at a much smaller scale with higher specific costs. At the farm level through biomethane production many countries, including Romania, could additionally reduce NG import dependency by including the synthetic fertiliser production capacities in improvement and marketing of digestate, or extract of macro-nutrients for bio-fertilizers

REFERENCES

- Adnan, A.I., Ong, M.Y., Nomanbhay, S., Chew, K.W. and Show, P.L., (2019). Technologies for Biogas Upgrading to Biomethane: A Review. *Bioengineering*, 6(4), p.92. <https://doi.org/10.3390/bioengineering6040092>
- Ahrens, T. and Weiland, P. (2007). Biomethane for future mobility. *Landbauforschung Völkenrode* 57(1), pg. 71-79
- Alberici, S., Toop, G., Monchen, B., Peeters, S. and Peterse, J. (2024). *Biogases towards 2040 and beyond. A realistic and resilient path to climate neutrality. Guidehouse Europe Lt, EBA -European Biogas Association.*
- Alberici, S., Wouter Grimme, W. and Toop, G. (2022). *Biomethane production potentials in the EU. A Gas for Climate report, Guidehouse Netherlands B.V.*
- Ammenberg, J., Gustafsson, M., O'Shea, R., Gray, N., Lyng, K-A., Eklund, M. and Murphy, J.D. (2021). Perspectives on biomethane as a transport fuel within a circular economy, energy, and environmental system. *IEA Bioenergy Task* 37:12.
- Angelidaki, I., Treu, L., Tsaepkos, P., Luo G., Campanaro, S., Wenzel, H. and Kougias, P. (2018). Biogas upgrading and utilization: Current status and perspectives. *Biotechnology Advances, Volume* 36, Issue 2, 452-466. doi.org/10.1016/j.biotechadv.2018.01.011.
- Ardolino, F., Cardamone, G.F., Parrillo, F., Arena, U. (2021). Biogas-to-biomethane upgrading: A comparative review and assessment in a life cycle perspective. *Renewable and Sustainable Energy Reviews, Volume* 139, 110588, <https://doi.org/10.1016/j.rser.2020.110588>
- Arnau, A.S. (2025a). *European biomethane capacity hits 7 bcm – stronger policy support needed to sustain momentum. EBA- European Biogas Association, https://www.europeanbiogas.eu/news/european-biomethane-capacity-hits-7-bcm-stronger-policy-support-needed-to-sustain-momentum/*
- Arnau, A.S. (2025b). *EBA Statistical Report 2025, https://www.europeanbiogas.eu/news/eba-statistical-report-2025/*
- Bauer, F., Hulteberg, C., Persson, T., & Tamm, D. (2013). *Biogas upgrading - Review of commercial technologies.* (SGC Rapport; Vol. 270). Svenskt Gastekniskt Center AB.
- Boglárká (Bogi), M. (2025). *Europe's biomethane landscape: Between ambition and reality, SUERF Policy Note, No 384*
- Börjesson P. et al. (2016). *Methane as vehicle fuel – A well-to-wheel analysis (MetDrive).* Report No 2016:06, f3. The Swedish Knowledge Centre for Renewable Transportation Fuels, Sweden, available at www.f3centre.se.
- EBA- European Biogas Association (2020). *European Biogas Association Statistical Report: 2019 European Overview.* Brussels, Belgium.
- Edwards, R., Larive, J.-F., Rickeard, D., Hass, H., Lonza, L., Maas, H., (2014). *Well-To-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context.* Publications Office of the European Union, Luxembourg. [doi:10.2790/9553](https://doi.org/10.2790/9553)
- EIP-AGRI Project, (2023). *Practice Abstract - Research and innovation. T6 METHANE POWER, https://eu-capnetwork.ec.europa.eu/projects/practice-abstracts/t6-methane-power_en*
- Energy Magazine, (2024). *România și potențialul său de producere a biometanului, https://energyexpo.ro/ro/energy-expo-2024-romania-si-potentialul-sau-de-producere-a-biometanului/*
- European Comission (2021). *Biomethane Fiche- Romania (2021).*
- Directorate-General for Energy, EU (2025). *5 things you should know about biogas and biomethane, https://energy.ec.europa.eu/news/5-things-you-should-know-about-biogas-and-biomethane-2025-10-09_en*
- de Hullu, J., Maassen, J.I.W., van Meel, P.A., Shazad, S., Vaessen, J.M.P. (2008). *Comparing different biogas upgrading techniques.* Eindhoven University of Technology, 2, 65-66
- Gkotsis, P., Kougias, P., Mitrakas, M., Zouboulis, A. (2023). Biogas upgrading technologies – Recent advances in membrane-based processes. *International Journal of Hydrogen Energy, Vol. 48, Issue* 10, 3965-3993, <https://doi.org/10.1016/j.ijhydene.2022.10.228>
- Godoy, V., Martín-Lara, M.A., García-García, G., Arjandas, S., Calero, M. (2024). Environmental

- impact assessment of the production of biomethane from landfill biogas and its use as vehicle fuel. *Renewable Energy, Volume 237*, Part B, <https://doi.org/10.1016/j.renene.2024.121685>.
- Green, P. (2018). *Basics Of Biogas Upgrading*, BioCycle, <https://www.biocycle.net/basics-biogas-upgrading/>
- Gustafsson, M., Svensson N., Gustafsson M., Svensson N. (2021). Cleaner heavy transports e Environmental and economic analysis of liquefied natural gas and biomethane. *Journal of Cleaner Production* 278.
- Hurtig, O., Buffi, M., Besseau, R., Scarlat, N., Carbone, C., Agostini, A. (2025). Mitigating biomethane losses in European biogas plants: A techno-economic assessment. *Renewable and Sustainable Energy Reviews. Volume 210*.
- IEA - International Energy Agency (2025a). *Outlook for Biogas and Biomethane, A global geospatial assessment, World Energy Outlook Special Report*, <https://www.iea.org/reports/outlook-for-biogas-and-biomethane>
- IEA - International Energy Agency (2025b). *Renewables 2025*, IEA, Paris <https://www.iea.org/reports/renewables-2025>
- IRENA (2018). *Biogas for road vehicles: Technology brief*, International Renewable Energy Agency, Abu Dhabi
- Kabeyi, J.B.M., Olanrewaju A.O. (2024). Chapter- *Biomethane Production and Applications*. In *Anaerobic Digestion - Biotechnology for Environmental Sustainability*. IntechOpen. <https://doi.org/10.5772/intechopen.112059>
- Kunak AIR (2025). *Biomethane and biogas: production, uses and environmental monitoring*, <https://kunakair.com/biomethane-and-biogas/>
- Laumann, S. (2025). *Biomethane -The renewables all-rounder*, <https://www.envitec-biogas.com/plant-construction/biomethane#>
- Mohammadpoura, H., Cheng K.Y., Pivrikas, A. and Ho, G. (2024). A review of biogas upgrading technologies: key emphasis on electrochemical systems. *Water Science & Technology, Vol 91*, No 2, 93, doi: 10.2166/wst.2024.394
- Nagy, D., Princz-Jakovics, T. (2025): *Biogas regulatory frameworks in Europe: Comparative analysis of biomethane usage in transport*. Energy Reports, Volume 13, <https://www.sciencedirect.com/science/article/pii/S2352484725003129>
- Prussi, M., Padella, M., Conton, M. and Postma, E.D. (2019). Review of technologies for biomethane production and assessment of EU transport share in 2030. *J. Clean. Prod.* 222, 565e572. <https://doi.org/10.1016/j.jclepro.2019.02.271>.
- Rehman A., Qyyum, M.A., Qadeer, K., Zakir, F., Ding, Y., Lee, M. and Wang, L. (2020). Integrated biomethane liquefaction using exergy from the discharging end of a liquid air energy storage system. *Applied Energy, Volume 260*, <https://doi.org/10.1016/j.apenergy.2019.114260>.
- Snam - Società NAzionale Metanodotti (2025). Biomethane. <https://www.snam.it/en/our-businesses/biomethane.html>
- Tratzi, P., Torre, M., Paolini, V., Tomassetti, L., Montiroli, C., Manzo, E., Petracchini, F. (2022). *Liquefied biomethane for heavy-duty transport in Italy: A well-to-wheels approach*. Transportation Research Part D: Transport and Environment Volume 107, 103288
- Todorović, I. (2025). *Romania preparing to include biomethane in gas grid*. <https://balkangreenenergynews.com/romania-preparing-to-include-biomethane-in-gas-grid/>
- Vale, S. (2025). *T7.270 Methane Power on sale*. Profi The Farm Machinery Magazine, UK
- Vylupek, L., Barrio Castro, L.B., Rajnoha, M., Zarádička, M., Sova, J. (2023). *The future of biomethane. Identifying renewable, environmentally friendly substitutes for natural gas*. <https://www.adlittle.com/mx-en/insights/viewpoints/future-biomethane>
- Weiland, P. (2003). *Production and energetic use of biogas from energy crops and wastes in Germany*. Appl Biochem Biotechnol. 109(1-3):263-74. doi: 10.1385/abab:109:1-3:263. PMID: 12794299.
- Zhao, Q., Leonhardt E., MacConnell, C. Frear, C., Cen, S. (2010). *Purification Technologies for Biogas Generated by Anaerobic Digestion*. CSANR Research Report 2010 – 001 Climate Friendly Farming Chapter 9, Compressed Biomethane
- *** (2026): *Biomethane Market Size, Share & Industry Analysis, By Feedstock, By Production Method, By Application, and Regional Forecast, 2026-2034*, <https://www.fortunebusinessinsights.com/industry-reports/bio-methane-market-100272>
- ***Eurostat (2022): *Energy Balance*
- ***<https://agriculture.newholland.com/en-gb/europe/products/agricultural-tractors/t7-270-methane-power-with-plm-intelligence>
- ***<https://cngeurope.com/countries/romania/>
- ***<https://www.engie.com/en/activities/renewable-energies/biogas-biomethane>
- ***<https://www.europeanbiogas.eu/publication/european-biomethane-map-2025/>